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THE PRACTICAL AERIAL HANDBOOK

Books on Radio and Television Servicing
by Gordon J. King

F.M. RADIO SERVICING HANDBOOK

RADIO AND AUDIO SERVICING HANDBOOK

RADIO AND TELEVISION TEST INSTRUMENTS

TELEVISION SERVICING HANDBOOK

THE HI-FI AND TAPE RECORDER HANDBOOK

SERVICING WITH THE OSCILLOSCOPE

RAPID SERVICING OF TRANSISTOR EQUIPMENT

In preparation

COLOUR TELEVISION SERVICING

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Preface to Second Edition

I AM very pleased to have had this opportunity of adding some information on one or two new aerial designs, of incorporating some suggestions made by readers and reviewers and making a couple of minor corrections to the text.

Since composing the first edition, the trend towards wideband, high-gain aerials has been accelerating. Soon the whole country will be within effective range of regional groups of four u.h.f. transmitters. It will then be possible for the majority of viewers to obtain BBC1, BBC2 and ITV1 on one aerial system. Later there will be a fourth programme—occupying the fourth channel of each regional group—possibly catering for ITV2 or, perhaps, something "educational". All programmes will be in monochrome and colour, the majority eventually being colour-encoded. Outright redundancy of the v.h.f. channels is unlikely, however, for these could be re-engineered to cater for 625-line monochrome and colour programmes, possibly later serving those areas badly shielded from the u.h.f. signals.

Finally, thanks to all the readers of the first edition and for the frank—though mostly highly encouraging—reviews.

G. J. K.

Brixham, Devon.

AUTHOR'S NOTE

A merger of Antiference and Belling and Lee television aerial interests occurred on 1st May, 1968, and a consolidated Antiference/Belling and Lee range of aerials was launched by Antiference on 1st September, 1968. This was in accordance with a promise made by Antiference to integrate the two ranges of aerials following the merger.

Preface to First Edition

RADIO and television aerials are vitally important items of equipment for both transmission and reception. Transmitting aerials, however, pose problems of their own, and it must be made clear at the outset that this book is intended to deal solely with receiving aerials—principally though not entirely those for use with domestic sets.

Without an efficient aerial system no receiver, even the most expensive, can attain its best performance. Indeed, a great many expensive radio and television receivers now in use yield mediocre results simply because insufficient attention has been paid to this matter.

In days gone by, the aerial system was important because headphones were actually powered by the signals abstracted from the radio wave by the aerial. Today's sets are capable of amplifying weak aerial signals many thousands of times. When amplifications of this magnitude are utilized, the smallest trace of signal is rendered sufficiently powerful to incite some response in the set, which is why modern sets will usually produce some kind of result from nothing more than an odd length of wire dangling from the aerial socket.

Many thousands of sets are working under these extremely inefficient conditions, both owners and (too often) servicing technicians being unaware of the vast difference that could be made by using a good aerial system. These sets struggle to pull in as much signal from a poor aerial as possible. In so doing they themselves generate interfering noise signals which show up as a crawling grain pattern on a television picture or as a hiss on sound. Weak aerial signals also aggravate the effects of external interference, and electrical radiations are far less likely to produce annoying crackles and whistles on sound or patterns and flashes on vision when the aerial is delivering signals strong enough to overwhelm them.

Of course, many viewers and listeners to the BBC's frequency-modulated programmes on Band II have to make do with very inferior indoor aerials because estate owners and local councils prohibit the erection of efficient outside aerials. Also, some flat dwellers are denied the use of good aerials because of the difficulty of erecting hosts of individual aerial systems on the communal building in which they live. The communal or shared aerial

represents one way out of this trouble, and it is pleasing to report that many councils and estate owners are now installing such systems. They are based on a single aerial array which feeds all the dwellings concerned.

The fact is that there is nothing to replace a well-designed, efficient aerial system. For reception on medium and long waves the highly efficient ferrite rod aerial has replaced the former long-wire aerial, carried on masts in the garden. But ferrite rod aerials are not suitable for reception in the v.h.f. or u.h.f. bands, though development work is being undertaken on a special ferrite rod aerial for the radio programmes in Band II. Even if this eventually becomes a commercial proposition, however, aerials will still be required for television reception.

This book gives a grounding in essential aerial theory but it is not a textbook. The list of contents shows what practical matters are discussed, but it may be mentioned here that appendices have been included giving details of aerials for the benefit of enthusiasts who like to experiment and make their own systems, and much other data given to help the servicing engineer, the radio dealer, the student and the amateur operator and home constructor.

I offer sincere thanks to the many manufacturers of aerials and associated equipment who have generously helped in the preparation of this book by supplying equipment for experimentation, photographs and details of equipment. It has naturally not been possible to mention the products of all firms engaged in the aerial industry, but much of the information presented has been drawn from the industry as a whole, which I gratefully acknowledge.

My special thanks are offered to Messrs. Mullard Ltd. and Mr. Brian Whale for permission to publish the design of a Mullard u.h.f. aerial amplifier, to Mr. Charles Bovill for details of his filter unit and other help, and to Mr. G. N. Adama (amateur radio station PA/FB) and Mr. J. J. Mink, both of Holland, for their DX television reception pictures and equipment details. My thanks also go to Mr. Sykes of J-Beam Aerials Ltd., Mr. Stallworthy of Antiference Ltd., Mr. Faithful of Thorn Electronics Ltd., Mr. Evans of Teleng Ltd., Mr. Kharbanda of Labgear Ltd., Mr. Redgrave of Belling & Lee Ltd., and to many other friends in the industry.

Lastly, I venture to remind readers that this is the sixth volume in my series of practical books on electronics. It has been designed to supplement the other volumes, although certain of them contain chapters on particular aspects of aerial work. The present book should prove a useful companion to these other handbooks on radio, television and audio engineering.

G. J. K.

Brixham, Devon.

CHAPTER 1

Propagation of Radio Waves

IT is the aim of this book to deal with aerials and their problems in a thoroughly practical manner, but radio aerials form one of those subjects which cannot be properly understood without some grounding in theory. In this chapter, therefore, we shall consider the broad theory of wave propagation—that is, how electromagnetic energy is conveyed through space—and in the next chapter describe the principles of aerial and feeder design. Those who wish to make a more thorough study of these matters are recommended to read one of the standard textbooks on aerial theory.

An aerial is a device which can be used to either transmit or receive radio (or television) waves. The receiving function of an aerial is the reciprocal of its transmitting function, which simply means that an efficient aerial is good for either transmitting or receiving, while a poor aerial is inefficient in both respects. Although we are primarily interested in aerials for reception, it is, nevertheless, useful to start by considering the functioning of a transmitting aerial.

A transmitting aerial may be defined as an electrical conductor of specific design. It acts as a "load" to the transmitter's radio-frequency (r.f.) power amplifier at a particular frequency or range of frequencies. As an electrical conductor, it is endowed with distributed inductance and capacitance and therefore behaves as a resonant circuit. Its characteristics—in conjunction with the ether through which radio waves are propagated—are such that it serves as an outlet for the high-frequency energy produced by the transmitter. The aerial, in fact, "loads" the transmitter to the ether, and the better the loading or coupling, the more efficient the aerial.

Conversely, the greater the "grip" or coupling a receiving aerial has to the ether, the greater is its efficiency and the greater the signal energy it will abstract from passing radio waves.

"Ether" is a term in popular use, though no one can say what it is. It was once thought of as a kind of invisible substance permeating space through which radio waves forced their way. Nowadays we know that these waves will traverse empty space—nothingness. Whatever its nature, it is well known that the ether has a "conductivity" to all forms of electromagnetic energy.

Radio waves are only one manifestation of electromagnetic energy. Others are light waves, infra-red waves, ultra-violet waves, X-rays, heat rays, cosmic rays and the lethal radiation emitted by radioactive materials (alpha rays, etc.). Which form electromagnetic energy takes depends upon its frequency. Thus, we have a vast range or spectrum of electromagnetic radiation from low to infinitely high frequencies in which each of the types of radiation mentioned above occupies a particular portion of the spectrum. Those waves in which we are mainly interested, namely the radio waves, occupy a very narrow band of frequencies at the lower end of the spectrum.

The whole spectrum is depicted (not to scale) in Fig. 1.1, and this also includes the audio frequencies, which do not possess the property of traversing the ether but produce sound vibrations in air. The radio waves portion of the spectrum is sub-divided into smaller bands or groups of frequencies, and these are listed in Table 1.1. Another way of defining these frequencies is by wavelength, and the table gives both definitions. It may be noted that these definitions are those internationally adopted and given in the International Radio Regulations (Geneva), which came into force in 1961. The definitions are the same as those used in the Telecommunications Glossary of Terms (BS 204), which has been issued by the British Standards Institution.

The meaning of the frequency-band abbreviations is as follows: v.l.f., very low frequency; l.f., low frequency; m.f., medium frequency; h.f., high frequency; v.h.f., very high frequency; u.h.f., ultra high frequency; s.h.f., super high frequency; and e.h.f., extra high frequency.

Frequency is signified by Hz (or c/s) which means Hertz or cycles per second; by kHz (or kc/s), meaning thousands of Hertz (k standing for "kilo" or 10^3); by MHz (or Mc/s), meaning millions of Hertz (M standing for "mega" or 10^6); and by GHz (or Gc/s), meaning thousand-millions of Hertz (G standing for "giga" or 10^9).

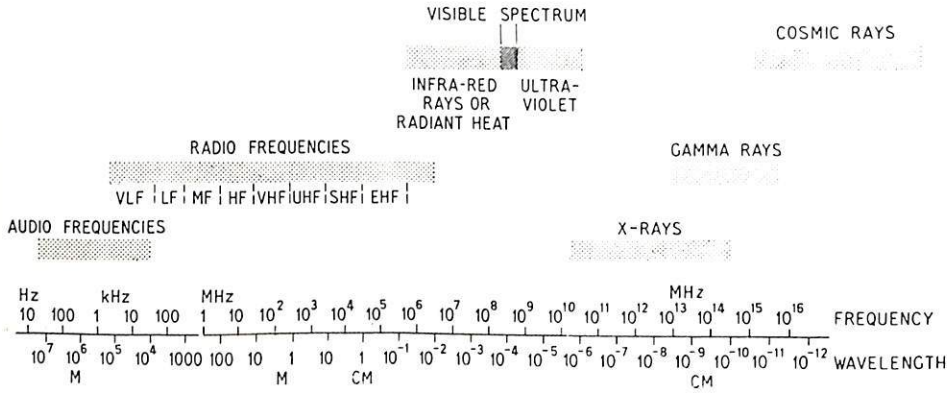


FIG. 1.1. *The electromagnetic wave spectrum.*

Table 1.1

THE RADIO WAVEBANDS

Frequency Band	*Frequency*	*Wavelength*	*Waveband Definition*
v.l.f.	3 to 30 kHz	100,000 to 10,000 m	myriametric
l.f.	30 to 300 kHz	10,000 to 1,000 m	kilometric
m.f.	300 to 3,000 kHz	1,000 to 100 m	hectometric
h.f.	3 to 30 MHz	100 to 10 m	decametric
v.h.f.	30 to 300 MHz	10 to 1 m	metric
u.h.f.	300 to 3,000 MHz	1 to 0·1 m	decimetric
s.h.f.	3 to 30 GHz	10 to 1 cm	centimetric
e.h.f.	30 to 300 GHz	1 to 0·1 cm	millimetric
e.h.f.	300 to 3,000 GHz	0·1 to 0·01 cm	decimillimetric

The frequency bands in which we are interested mainly are so-called long waves from about 150 to 285 kHz (2,000 to 1,185 metres), medium waves from about 535 to 1,600 kHz (560 to 187 metres), and short waves from about 2 MHz to 30 MHz (about 120 to 10 metres). The v.h.f. and u.h.f. bands are used for f.m. radio and television, and are defined in Chapter 2. Incidentally, the two alternative methods of measurement shown in the table may imply that the only significant characteristics of radio waves are their frequency and wavelength. Actually, the prime properties of a radio wave are frequency, intensity, direction of propagation and plane of polarization.

RADIO WAVES

A radio wave is created by a strong oscillation produced by the power amplifier of the transmitter. This oscillation is coupled to the ether by way of the aerial. One may consider that the ether is put into a state of "oscillation". The resulting radio waves vary in intensity with the frequency of the oscillatory current supplied by the transmitter. They are, therefore, alternatively positive and negative, and may thus be represented by the familiar sine wave curve.

However, radio waves are not really invisible sine waves rushing through the ether away from the transmitting aerial. The waves move speedily, it is true. In fact, they travel with the velocity of light, which is—from the practical point of view—of the order of 300,000,000 metres per second (the

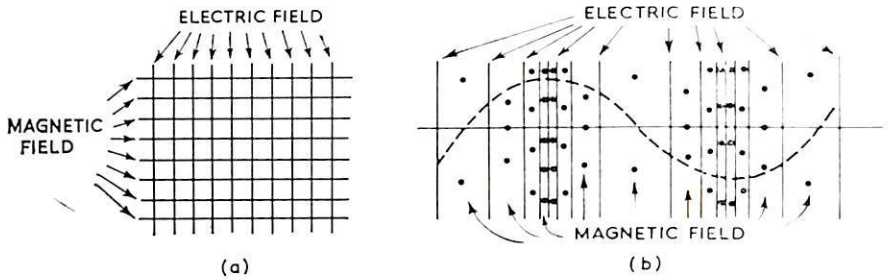


FIG. 1.2. *Diagrammatic representations of a radio wave. At* (a) *is the wavefront advancing towards the observer from out of the page, while at* (b) *is signified a passing radio wave. The changing polarities of the electric field (vertical lines) and the magnetic field (dots) are indicated by the compression and expansion of the lines and the increase and decrease in the number of the dots. The wave translated to a sine wave is given in broken-line.*

theoretical speed is a very small fraction below this). Radio waves are composed of magnetic and electric components at right-angles to each other and also at right-angles to their direction of travel through the ether. Half the energy of the waves consists of electric energy and the other half of magnetic energy. Hence the term electromagnetic waves.

If one could see an *advancing* radio wave it would probably look something like the diagram in Fig. 1.2 (*a*). This would be termed the "wave front". Here is shown the electric and magnetic components at right-angles to each other, and since the wave front is advancing out of the page, the direction of travel is also at right-angles to the electric and magnetic components (or "fields", as they are sometimes called).

A side view of a radio wave is shown in Fig. 1.2 (*b*). This is the sort of effect that would occur if one could see a *passing* radio wave. Here the electric field is represented by the vertical lines and the magnetic field by the dots. Since the radio wave is a product of oscillatory energy from the transmitter, the polarity of the fields is changing after the style of a sine wave. This is signified in the diagram by the alternate compression and expansion of the electric field and by the increase and decrease of the number of dots representing the magnetic field. The translation of these changing polarity effects is shown as the broken-line sine wave in Fig. 1.2 (*b*). It is, indeed, the changing polarities of the fields that sustain a radio wave in the ether.

WAVELENGTH AND FREQUENCY

The distance in the ether taken by one complete cycle of radio wave, called the "wavelength", is equal to the velocity of the wave divided by the frequency of the oscillatory energy radiated by the transmitter. The wavelength is measured in metres when the velocity of the wave in metres (i.e.,

300,000,000 metres/sec.) is divided by the frequency in Hz. A Greek letter, lambda (λ), is used as the wavelength symbol. Thus:

$$\lambda = \frac{300{,}000{,}000}{\text{Hz}} = \frac{300{,}000}{\text{kHz}} = \frac{300}{\text{MHz}}$$

Clearly, then, a low-frequency wave has a long wavelength, while a high-frequency wave has a short wavelength. Diagrammatic representations of a wavelength and its sub-multiples are given in Fig. 1.3.

The intensity of the radio wave is a measure of its electric and magnetic amplitudes. The stress of the electric component in the ether is in terms of voltage (sub-multiples of the volt, in practice), while the root-mean-square (r.m.s.) value of the voltage of the waveform (i.e., 0·707 times the maximum voltage stress in the ether during a complete cycle) is equal to the r.m.s. voltage induced into a conductor 1 metre in length due to the magnetic field of the radio wave cutting the conductor at the velocity of light.

The strength of a radio wave is thus a function of both the electric and magnetic components. Without one there cannot be the other, and the wave is sustained by the electric component being produced due to the changing magnetic component. Furthermore, a radio wave has components of voltage and current, the former resulting from the electric field and the latter from the magnetic field. The ether is said to have its own characteristic impedance, this being equal to the electric component (or voltage) divided by the magnetic component (or current), usually given as E/H. The characteristic impedance of the ether (that is, free space) is 377 ohms.

FIELD STRENGTH

The field strength round a transmitting station is given in terms of microvolts per metre (abbreviated to μV/m, a μV or microvolt being one-millionth of a volt). The field strength is measured (and/or calculated) by a special field strength meter calibrated direct in terms of μV/m in conjunction with an aerial of specific characteristics supported at a certain height above the earth. An example of a field strength map is given in Fig. 1.4. This relates to the Channel 5 BBC1 television transmitter at Wenvoe, South Wales. The field strength contours (in μV/m) represent average values and variations in signal intensity often occur at individual points, particularly in hilly and built-up areas.

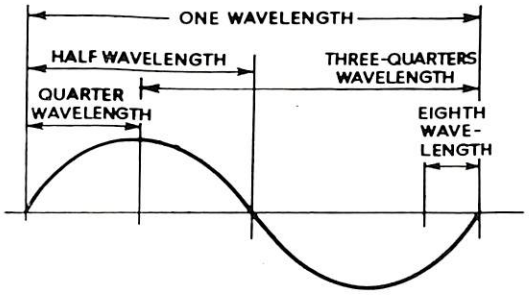


FIG. 1.3. *A wavelength and its sub-multiples.*

It should be noted that the method of calculating the field strength in μV/m goes back to the early days of radio, before v.h.f. and u.h.f., when only long and medium waves were in use. In those days receiving aerials were rarely tuned, but were so-called "long-wire" aerials. The longer the wire, the greater was found to be the signal pickup. This is not so in these days of tuned v.h.f. and u.h.f. aerials. Nevertheless, the amount of signal induced into a tuned v.h.f. or u.h.f. aerial is directly related to the field intensity, even though it is given in μV/m. More is said about this in Chapter 2.

Of course, the minimum field strength required to give satisfactory reception is governed by the sensitivity of the receiving equipment and by the type and height of aerial used. It also varies with the amount of interference that is present, as we shall see.

Clearly, the intensity of the signal field is governed by the strength of the oscillations produced by the power amplifier of the transmitter and by the efficiency of the transmitting aerial. By the use of a directional aerial, it is possible to make the wave intensity greater in one or more directions than another.

The direction of travel of a radio wave through the ether or free space depends upon the relative direction of the lines of electric and magnetic field. If the direction of the electric *or* magnetic field is reversed, the direction of wave travel is also reversed, but if both the fields are reversed, the direction of travel of the wave is unchanged.

POLARIZATION

A radio wave has a specific polarization characteristic. A wave is vertically polarized when the lines of the electric field are vertical and horizontally polarized when the lines of the electric field are horizontal. Thus, a wave is polarized in the direction of the electric field.

A vertically polarized wave requires a vertical aerial for abstracting energy from the wave (because signal is induced by the magnetic component *cutting* the conductor), but a slot type of aerial (see Chapter 2) requires to be horizontally disposed to respond to a vertically polarized signal. This is because a slot aerial responds to the electric component of the signal.

It is possible to produce radio waves with circular or elliptical polarization. Such waves, however, are not as yet used for radio and television, as we know it. Nevertheless, vertically or horizontally polarized waves can approach a circular or elliptical polarization characteristic due to reflection and diffraction. The effective polarization may also be shifted some degree off the vertical or horizontal for the same reasons.

Radio waves travel away from the transmitting aerial in more or less straight lines, but waves of certain frequencies do have a tendency to bend due to diffraction and their line of direction may be modified due to reflection.

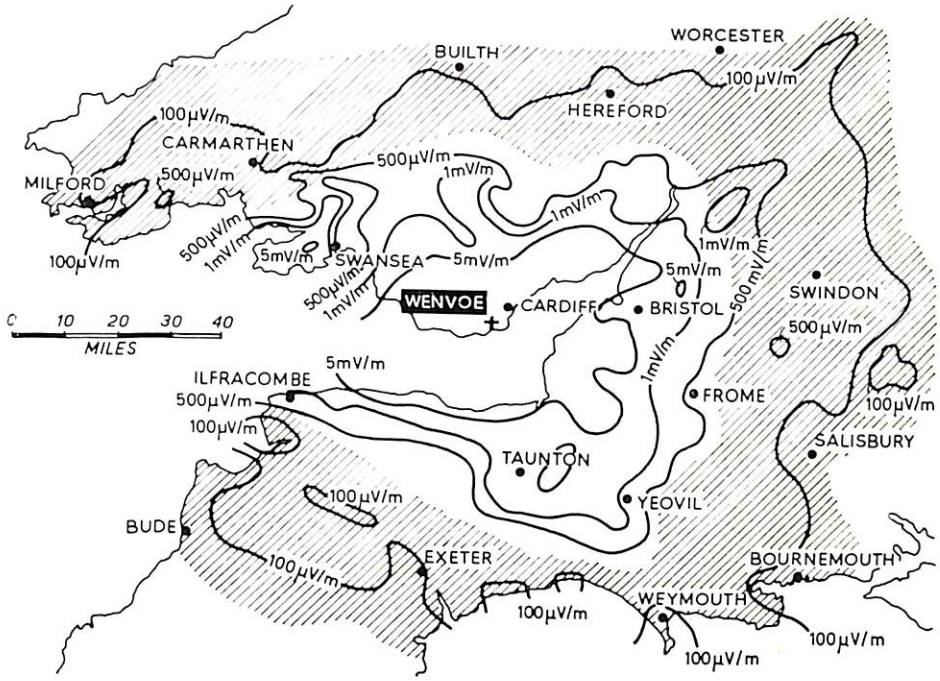


FIG. 1.4. *Field strength contour map of the BBC1 Wenvoe station on Channel 5.*

The waves are influenced by various factors in the ether between the transmitter and the receiver, and some waves may never reach their destination, or they may be so severely weakened (attenuated) during their journey as to be virtually useless at the receiving end.

From earth-bound transmitting aerials there are two main waves. One is the "ground wave" which travels along the surface of the earth, and the other is the "sky wave" which is propagated in the sky well above the earth.

GROUND WAVE AND SKY WAVE

The ground wave progressively reduces in intensity with distance from the radiating aerial due to absorption by the earth and spreading of the wave. The ground wave, in fact, induces charges in the earth which result in a power loss. These charges follow the ground wave and are continuously being replenished by it. The ground wave losses, therefore, are influenced by a number of factors including the conductivity of the earth, the frequency of the wave, the distance from the transmitting aerial, etc.

Ground wave losses increase with increase in signal frequency, and above about 1·5 MHz the losses are such that the service area is reduced to a few miles. Over sea, however, the losses are less. This makes m.f. and h.f.

communication possible between ships and from ship to shore up to 100-200 miles. Over land, ground propagation is limited to local services.

The sky wave is attenuated as the inverse of the distance travelled (the inverse-distance law) until it penetrates the ionized regions of the upper atmosphere, called the "ionosphere". On entering the ionosphere, the path of the wave may be bent, due to the refractive nature of the ionosphere, and the wave may return to earth at a distance related to its angle of departure and to the height of the ionized layer by which it is influenced. Indeed, a sky wave may return to earth at very great distances from the transmitter, this being the basis of long-distance radio communications.

The ionosphere may also be responsible for attenuating the waves above that corresponding to the inverse-distance law, depending upon the nature of the ionized layer and the frequency of the signal. On the other hand, the ionosphere may offer little attenuation of the wave beyond that of the inverse-distance law. The ionosphere then acts either as an almost perfect mirror or as free space to the signal.

As the signal frequency is increased the ionosphere tends less to influence the wave. Reflections from the ionosphere at v.h.f. are rare while at u.h.f. the signals pass on through the ionized regions and are lost in space.

The critical frequency above which the ionosphere loses its refractive characteristics is governed by the electron density of the ionized layers. In turn, the electron density of the layers is governed by the time of day and the seasons of the year. The critical frequency during the day is somewhat higher than that during the night, and there is also a tendency for the frequency to be higher during the summer months and during the active sun-spot period. This means that v.h.f. signals are more liable to suffer reflective effects from the ionosphere during the days of the summer, especially when sun-spot activity is at its height.

PROPAGATION

The propagation of v.l.f. waves is essentially by the ground wave. This is because of the very small earth losses at such frequencies. This kind of propagation is not influenced very much by day-night and seasonal variations in the ionosphere, and consistent, fade-free reception is possible at substantial distances from the transmitter.

The propagation of l.f. and m.f. waves is by both the ground wave and the sky wave. At distances from the transmitter where the ground wave is almost completely absorbed, the received signal energy comes by way of the sky wave. These relatively low frequencies are readily reflected by the ionosphere with very little abnormal loss. However, this propagation is considerably affected by the conditions in the troposphere, and severe fading can be experienced due to day-night and seasonal ionospheric variations.

Cyclic fading effects are sometimes experienced due to like variations in the ionosphere.

Propagation of m.f. waves is by ground waves for medium distance transmissions and by sky waves for greater distance transmissions. However, the sky wave becomes active only during the hours of darkness (starting at dusk). This is because the ionosphere has virtually no reflective influence on the signals during the daylight hours.

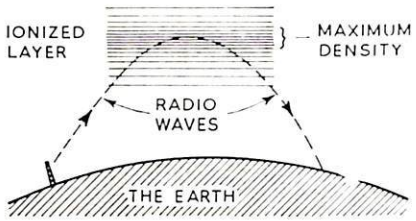
While the daytime coverage of a station in the l.f. and m.f. classification is relatively small, these are useful frequencies for relatively local broadcasting since the received signals due to the ground waves are always consistent, day after day, winter and summer, year in year out. Such frequencies, of course, are employed by the long and medium wave broadcasting stations of the world.

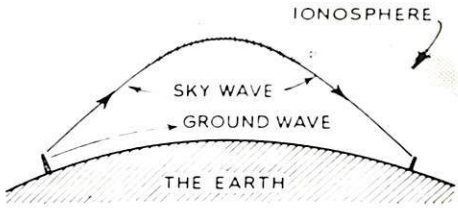
Trouble starts so far as local reception is concerned when night falls, for then more distant signals start coming in due to sky wave propagation. The effect is severe towards the high-frequency end of the medium wave band, around 1 to 1·5 MHz. Signals which originate at points far beyond the range of the daytime signals badly interfere with signals from the local stations which during the hours of daylight are propagated by the ground waves. Signals from the local stations are then, of course, propagated via sky waves to more distant parts and cause interference in other countries.

On the other hand, m.f. listeners may rely on sky wave signals for their evening broadcast entertainment. Typical in this respect are those in Great Britain who enjoy such stations as Radio Luxembourg. Signals from stations which operate between 1 and 1·5 MHz can only be received after dusk, but they are often badly mutilated by interference from signals originating in other countries using the same or a near frequency. The results are very disturbing, to say the least, and the background whistles, crackles and monkey-chatter effects are often made worse by fading and disconcerting distortion which itself fades in and out as the signals themselves fade. To understand why these things happen, we shall now have to look a little more closely at the nature of the ionosphere.

THE IONOSPHERE

The upper regions of the earth's atmosphere are composed of free electrons and positive and negative ions in a rarefied gas. These regions become ionized into layers due to radiations from the sun and from outer space. The electrons in these layers are chiefly responsible for the influence on radio wave propagation. The influence increases with increase in electron density. The electron density rises towards the middle of the layers, and the radio waves are refracted due to this and thus return to earth, as shown in Fig. 1.5.





(Left) FIG. 1.5. *How the increasing electron density in the ionosphere refracts or bends waves.* (Right) FIG. 1.6. *The ionosphere is exploited for long-distance radio communication in conjunction with the sky wave. Note the rapidly attenuated ground wave.*

In other words, the ionized layer has a sort of "refractive index" so far as the radio wave is concerned, causing the wave to bend. This is somewhat similar to an optical lens, which bends light rays, or to a mirror which "reflects" light rays. Indeed, refraction and reflection have almost the same meaning relative to certain aspects of the ionosphere, for if a radio wave takes a path of normal incidence to the ionized layer it is reflected back along the same path.

There are several ionized layers at various heights above the earth, two being named after their discoverers, Kennelly-Heaviside and Appleton. Others are referred to by letters of the alphabet. The lowest layer is called the "D" layer, and layers above this are called "E" and "F" layers.

These layers are all affected to some extent by day and night conditions, by the seasons of the year and by conditions in outer space and on the sun. The "D" layer, for instance, travels round the earth with the sun, and thus exists only during the hours of daylight. This layer mostly affects daytime sky waves. It tends to absorb these and is one of the reasons why m.f. fading is not troublesome during daylight hours.

The critical frequency of the "E" layer reaches a maximum of about 3·7 MHz when the sun is at its height during the summer, but its refractive effect almost completely disappears after sunset.

The "F" layer is probably the most important so far as very long distance propagation is concerned. During the hours of daylight, this splits into two layers, the lower called "F_1" and the upper "F_2". The "F_2" layer has the highest critical frequency, and is the layer exploited for long distance communications.

Unfortunately, the refractive and reflective properties of the ionized layers are not consistent even during the time when the layers are fully active. This means that radio waves arriving at a receiver by way of the ionosphere could be affected in various ways by the conditions in the ionosphere. For instance, the path length of the wave sometimes alters continuously due to random changes in the refractive conditions and height of the layer.

Fig. 1.6 shows how the ionosphere is used in the propagation of radio waves, and how distances far in excess of those possible by the ground wave are achieved.

FADING

It often happens that a receiving aerial picks up signals from the same transmitter which have travelled via two or more routes of different length. This is typified in Fig. 1.7 (*a*), where it can be seen that at the receiving point are signals via the ground wave and via the sky wave. This condition is responsible for fading troubles because the phase of one signal relative to the other has a tendency continuously to change.

When the two signals are in phase they add together and give rise to an aerial signal which is proportional to their sum. However, if they are completely out of phase with each other (that is, one signal going positive while the other is going negative), the aerial signal is weakened by subtraction. If the two signals are completely out of phase and equal in amplitude, there is complete cancellation and no aerial signal. Normally, however, one signal is of greater strength than the other, so complete cancellation does not always occur. Nevertheless, the aerial signal rises and falls as the signals vary in phase relative to each other. This, of course, produces bad fading at the loudspeaker.

Another example of two waves which, although emanating from the same transmitter, follow different paths before arriving at the receiving aerial is shown in Fig. 1.7 (*b*). Here the two waves are sky waves from the ionosphere, one being refracted at a greater angle than the other.

It will be understood that more than two waves of different path length could be present in the receiving area. This complicates the fading problems. The phase of the waves will vary because of the varying path lengths.

There is another form of fading, already referred to, which gives rise to distortion. This is called "selective fading". It results from the fact that the

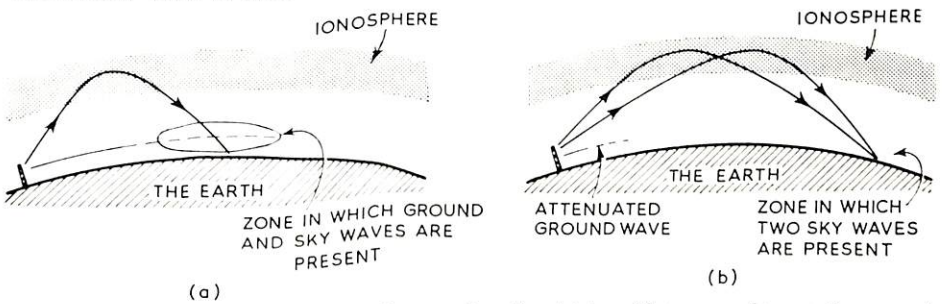


FIG. 1.7. *Causes of fading. At* (a) *two signals which add to or subtract from each other are present due to the sky and ground waves. At* (b) *the two signals are from sky waves taking different routes. Fading results from their phase changes.*

ionosphere affects radio waves of different frequency differently. A wave carrying information, such as music or speech, can be analysed into a number of frequencies comprising the carrier wave proper and the various sideband signals due to the modulation. Now, while a sideband of one frequency may be refracted by the ionosphere to give one path length, a sideband of a different frequency may be refracted in a slightly modified manner, resulting in this signal having a longer or shorter path length.

In effect, this means that the modulated signal at the receiver is somewhat decomposed or broken down into distorted sideband components. The distortion varies depending on the fading conditions of the ionosphere, but when the effect is at its height, reproduction is rendered almost meaningless.

H.F. PROPAGATION

The propagation of radio waves from about 1·5 to 30 MHz (short waves) depends almost completely upon the ability of the ionosphere to refract the sky wave back to earth in the receiving area without undue attenuation. This means, as we have seen from our discussion on the ionosphere, that h.f. reception is considerably affected by the conditions in the ionosphere, the time of the day or night and the period of the year.

Ordinarily, the ground wave weakens very rapidly with distance from the transmitter, making h.f. ground wave propagation virtually useless. However, for short-distance communications and communications over water frequencies up to about 3·5 MHz are sometimes adopted.

Sky wave h.f. propagation is also governed by the angle at which the radio waves are caused to enter the ionosphere. Special aerials, giving the optimum angle of entry, are thus employed for long-distance h.f. operations. For consistent long-distance h.f. communication a top frequency of around 26 MHz is employed. Higher frequencies may permit long-distance reception. American police cars, for example, have been heard in Great Britain at frequencies around 30 MHz at certain times when reception conditions have been just right. Similarly, the BBC television transmissions, around 45 MHz, have been received for limited periods as far afield as South Africa and Australia. These are "freak" reception conditions, however.

Very long-distance reception relies on the sky waves from the ionosphere re-entering the ionosphere after being reflected by the earth. This may happen several times, as shown in Fig. 1.8. In this case, the earth acts as a good reflector, the waves being returned to the ionosphere at an angle complementary to that at which they strike the earth.

Skip Distance. Reception in the h.f. bands is characterized by so-called "skip distance" effects. This is illustrated in Fig. 1.8. Here is shown a distance A-B where there is virtually no signal due to the sky wave. At point A, the signal is very strong owing to its angle of refraction from the ionosphere,

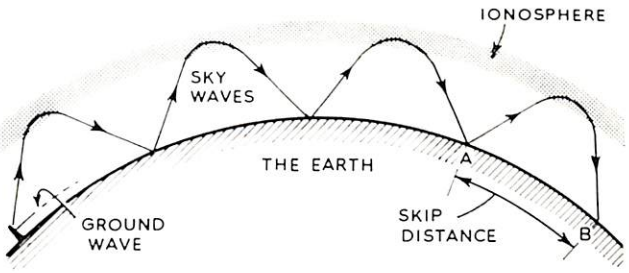


FIG. 1.8. *Illustrating skip distance. The sky wave refracted from the ionosphere "illuminates" an area round point A. At this point the signal is reflected back to the ionosphere, to return again at point B.*

and at this point the signal "illuminates" a certain area. It is then reflected up to the ionosphere again, to be lost until it arrives back at the earth and "illuminates" an area round point B.

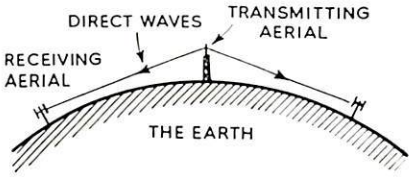
There are, of course, a number of skip distances in the diagram, and in some cases there may be only one skip distance, that being due to just a single hop via the ionosphere. The ground wave at h.f. fades away rapidly, as we have seen, which means that there will be no signal a few miles away from a h.f. transmitter. However, a number of miles later the signal will reappear due to reflection from the ionosphere (the first skip).

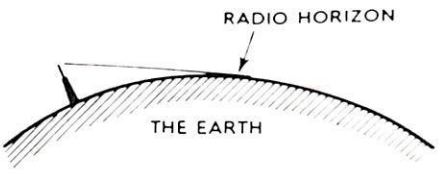
It is for this reason that some short-wave transmissions originating in Great Britain, for overseas service, are virtually impossible to receive locally, yet at their destination they are received loud and clear (probably with some fading due to ionospheric effects).

Owing to the manner in which the ionospheric conditions are influenced, as discussed earlier, the skip distance varies with time of day, with seasons and with conditions in outer space and on the sun. To compensate for the change in conditions during day and night, h.f. transmitting stations change frequency from time to time to ensure that the transmissions are received at distant places under the best possible ionospheric influence.

V.H.F. PROPAGATION

The propagation of v.h.f. signals differs somewhat from that of lower frequency signals. At v.h.f. the ground wave as such is speedily exhausted due to earth losses. However, the transmitting aerial tuning such frequencies is dimensionally small, which means that it can be erected on the top of a very tall mast, so that it is many wavelengths above the ground. Due to this, waves from the aerial follow almost straight, direct paths to the receiving aerials, as depicted in Fig. 1.9. These are sometimes called "space waves". It would seem that this mode of propagation would limit the transmissions to the distance fixed by the "radio horizon" (Fig. 1.10). This is not so, however, for the waves are bent due to a change in refractive index with change of height in the lower atmosphere. They are also bent due to diffraction, as shown in Fig. 1.11.





(Left) FIG. 1.9. *Since a v.h.f. aerial can be mounted at the top of a tall mast, it is many wavelengths above the surface of the earth, and signals are radiated from it direct to the receiving aerials, as shown. The signals so propagated are sometimes called "direct waves" or "space waves".* (Right) FIG. 1.10. *The "radio horizon" distance in miles is equal approximately to* 1·22 *times the square root of the height of the aerial in feet.*

The service area of a v.h.f. station is a little beyond the radio horizon distance between the top of the transmitting mast and the receiving aerial. For this reason it will be appreciated that the height of both the transmitting and the receiving aerial is very important at v.h.f. It can be shown that the radio horizon distance in miles is equal to 1·22 times the square-root of the height of the aerial in feet. Thus, the horizon distance from the top of a transmitting aerial 1,300 ft above sea level is about 43 miles, while the horizon distance from a 30 ft receiving aerial is about $6\frac{1}{2}$ miles. By adding together the two horizon distances, the "line-of-sight" distance between the two aerials is obtained (in this example, a little under 50 miles).

The Troposphere. In practice, reception is possible at distances in excess of this due to refraction and diffraction, as we have seen. However, beyond the line-of-sight distance reception is somewhat less consistent than within this distance. This is because of changes in the refractive index of the lower atmosphere, called the "troposphere" and not to be mistaken for the ionosphere, with changes in weather conditions. Under certain weather conditions, the troposphere affects v.h.f. signals in such a manner that they are propagated over distances far greater than accountable by ordinary bending of the waves. Such abnormal reception conditions are often brought about by long periods of fine weather. The rising heat from the surface of

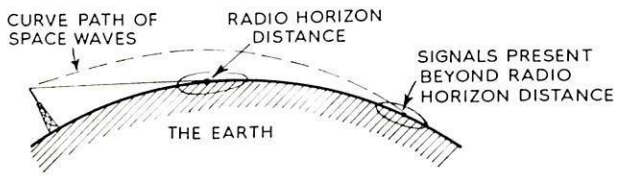


FIG. 1.11. *V.h.f. signals are propagated beyond the horizon distance because of bending of the waves as they pass through the troposphere, due to temperature and pressure changes with height above the surface of the earth and also because of diffraction at the surface. The signals thus tend to hug the curvature of the earth.*

the earth modifies the refractive index of the troposphere, and long-distance ducting of the waves in the troposphere frequently occurs.

CO-CHANNEL INTERFERENCE

This means that a v.h.f. station, such as a television station, produces signals well outside the normal 50-60-mile reception area. Indeed, television signals have been known to produce good pictures (and sound) at distances of the order of hundreds of miles from the station. This is all very well, but since the limited number of v.h.f. channels put over to television broadcasting need to be shared for country-wide television coverage, the reception of long-distance stations on a local channel can prove much of an embarrassment in terms of interference. This is called "co-channel interference", and its effect on a television picture is illustrated in Fig. 1.12.

The sharing of channel numbers is carefully planned by the authorities so that within the "service area" of any station signals from the distant stations are, under normal conditions of reception, so weak as to be imperceptible. However, during a period of abnormal reception conditions (often during the spring and summer), the signals from distant v.h.f. stations are received much more strongly. As illustrated, the resulting interference may take the form of regular horizontal bars moving up or down the picture (sometimes called "Venetian blind interference") or may form moire patterns (often referred to as "watered silk interference"). The sound may also be affected.

Co-channel interference is not equally troublesome on all channels. It is less intense on the higher number channels. This is because the higher v.h.f. frequencies are less affected by the troposphere. The interference is thus more troublesome on the BBC channels in Band I than on the ITV channels in Band III.

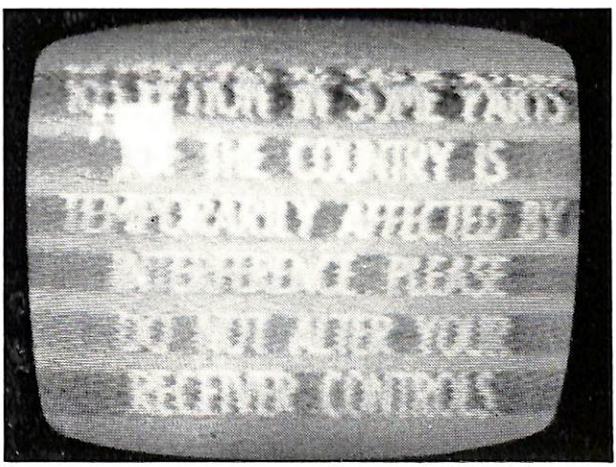


FIG. 1.12. *Co-channel interference on a television picture. This kind of interference is more troublesome on the lower-number Band I BBC channels than on the higher-number ITV channels.*

So far we have considered only the space wave at v.h.f. In addition to this there is a wave *reflected* by the ground. The ground reflected wave and the space wave are picked up by the receiving aerial, as shown in Fig. 1.13.

The ground wave has a cancellation effect on the space wave, as may be expected, but complete cancellation very rarely occurs owing to the difference in lengths of the paths and the fact that one signal is stronger than the other. Complete cancellation can occur, nevertheless, when the conditions are such that the path lengths and signal strengths are equal, or when there is a neutralizing combination of these two factors. Such generally happens, though, at sites very close to a transmitter and/or where the receiving aerial is close to the ground. The solution to this problem is to alter the height of the receiving aerial so as to eliminate the cancellation conditions.

It can be seen that height of the aerials plays a big part in the propagation of v.h.f. signals. The power of the transmitting station is less important relatively. The field strength due to a v.h.f. signal within the horizon distance can be expressed as:

$$E \text{ in mV/m} = 2{\cdot}85 \sqrt{P} \frac{h_t \, h_r}{\lambda d^2}$$

where P is the transmitted power (effective radiated power) in kW, h_t and h_r the heights of the transmitting and receiving aerials in metres, d the distance from the transmitting station in metres and λ the wavelength of the signal in metres. E is the signal voltage induced into a single dipole aerial. This expression shows that the field strength is directly proportional to the height of the aerials, while the strength rises only as the square root of the power increase. Thus, a power increase of four times, which is quite a lot of transmitter power, will only double the local field strength, while a four-times increase in aerial height will increase the local field strength by the same amount. The received field is inversely proportional to the *square* of the distance because of the counteracting effect of the ground reflected wave.

Normally, v.h.f. signals pass right through all the ionized layers of the ionosphere, including the F layers, at all times. During very abnormal ionospheric conditions, however, when sun-spot activity is at its height, v.h.f. signals may tend to come under the influence of the ionized layers and be refracted back to earth at remarkably great distances from the station.

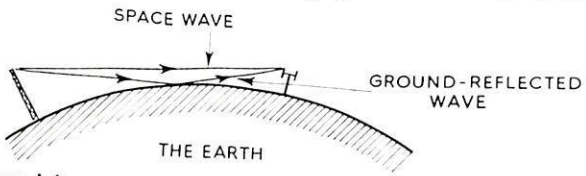


FIG. 1.13. *The receiving aerial picks up two signals, the space wave and the ground reflected wave. Under certain conditions, the ground reflected wave can result in signal cancellation at the aerial.*

As already mentioned, the BBC1 television signals on Channel 1 were received as far afield as South Africa during the summer of 1950. Such propagation is via the ionosphere. However, even very abnormal ionospheric conditions have little influence on signals of a frequency towards the top of the v.h.f. spectrum or in the u.h.f. spectrum. Signals of these frequencies may be affected by the troposphere, but the tendency for even this to happen diminishes with increase in frequency.

Mention here should be made of the exceptional reception of BBC Channel 1 picture and sound in Australia by George Palmer, some of whose tapes are in the BBC archives.

U.H.F. PROPAGATION

U.h.f. signals are propagated in a manner similar to that of v.h.f. signals. The transmitting aerial radiates space signals direct to the receiving aerials, but these signals are less curved than v.h.f. signals, meaning that they fail to "hug" the curved earth over such great distances. There is thus less fringe-area reception on the u.h.f. channels than on the v.h.f. ones. After the radio horizon distance, the signal virtually disappears. This is because u.h.f. signals tend to behave more like light rays than do signals of lower frequency.

While reception via the troposphere has been known to occur on the u.h.f. television channels, it is rare and there are very few reports of ionospheric propagation. Sky-bound u.h.f. signals easily penetrate the ionosphere and continue their journey through space where they are lost for ever!

Ground waves at u.h.f. are virtually dissipated before they are born due to the great earth losses at these frequencies. However, as with v.h.f. signals, ground reflected signals are present at u.h.f. which, under certain conditions, can result in cancellation effects at the receiving aerials, along the lines already discussed.

Diffraction. The higher their frequency, the more do radio waves behave like rays of light. At v.h.f. and low u.h.f., however, the signals are subjected to bending as the result of diffraction. This is illustrated in Fig. 1.14 (*a*), which shows a receiving aerial hidden from the transmitting aerial by a large hill. In spite of this, the receiving aerial picks up some signal due to the waves being bent or diffracted as they pass over the top of the hill.

At higher frequencies the diffraction effect is less, as shown in Fig. 1.14 (*b*). Here a receiving aerial on the wrong side of the hill would pick up virtually no signal, since the waves passing over the top of the hill are not bent sufficiently. In this case, the solution would be to mount the aerial on the top of the hill and feed signal to the receiver through low-loss coaxial cable. A low-noise booster amplifier may also be required to compensate for the signal losses in the cable. This technique would also be desirable in the

FIG. 1.14. *Diffraction. At* (a) *is shown how a receiving aerial hidden from the transmitting aerial by a hill may receive some signal due to the wave being bent down by diffraction as it passes over the top of the hill. The bending is less at higher frequencies, and on the u.h.f. channels a similarly placed aerial would receive no signal at all, as at* (b).

instance shown in Fig. 1.14 (*a*), for although the set would receive some signal due to diffraction, it would be weak and probably distorted and thus produce only a poor television picture or v.h.f. derived sound.

Shadow areas are thus more numerous at u.h.f. than at v.h.f., and even houses and trees can greatly attenuate signals on the u.h.f. channels. Large buildings can virtually cut the signal off altogether, and it has been known for the local u.h.f. field strength to vary between the seasons due to the growth of foliage on nearby trees during the summer months!

REFLECTION

Lower frequency waves exhibit fewer of the characteristics of light rays. Low-, medium- and high-frequency waves, for instance, readily pass through large solid objects, though the attenuation factor of the object rises with increase in frequency. V.h.f. and u.h.f. signals find it progressively more difficult to pass through such objects, and ultimately the object reflects the signal back towards its source, with the efficiency of reflection increasing with increase in frequency.

Generally speaking, any object which is not smaller than half a wavelength of the radio wave can act as a reflector, greater reflecting efficiency being achieved with metal objects. Nevertheless, stone, brick, wood and the like will also reflect signals, as will natural obstacles such as hills and mountains. Sometimes even clouds reflect signals, and passing aircraft exhibit similar effects. As the efficiency of reflection increases with increase in frequency and as there are many more objects of half-wave dimensions at u.h.f. than at v.h.f., it follows that reflections at u.h.f. are more numerous than at v.h.f. However, whether or not this is a problem so far as receiving u.h.f. signals is concerned is questionable owing to the fact that u.h.f. aerials can be made much more directional than lower frequency aerials and thus can be orientated to favour the direct signal and reject the reflected signals. This is considered in a later section.

A typical case of reflection is depicted in Fig. 1.15 (*a*). Here the receiving aerial is picking up the direct signal from the transmitting aerial along with

a second signal from the same station, via the reflecting gasometer. The reflected signal, of course, travels by a longer route than the direct signal and for this reason arrives at the receiving aerial a fraction of a second later.

GHOSTING AND FLUTTER

From the television point of view, superimposed on the picture produced by the direct signal is a secondary or "ghost" picture due to the reflected signal. The ghost picture is displaced from the main picture horizontally by a distance resulting from the time difference between the direct and reflected signals. Usually, the ghost picture is of considerably less contrast than the main picture because the reflected signal is that much weaker than the direct signal. However, the ghost picture may appear as a negative (white parts black and black parts white) image owing to reversal of phase of the reflected signal. In severe cases of ghosting—sometimes called "multipath interference" —the line lock of the receiver is weakened and made erratic in operation.

It is possible to compute the time delay of the reflected signal. On a 625-line television system, the active line scan takes about 53 μS. Now, suppose the ghost image is displaced by 1 in. from the main image and that the active width of the picture as a whole is 10 in. The 1 in. displacement time is equal to the picture width (10) divided by the displacement distance (1). This gives 10. Now by dividing the active line time (53) by 10 we get 5·3, which is the delay time in μS of the reflected signal.

From this it is possible to calculate the extra real distance travelled by the reflected wave. We have seen that radio signals travel at a speed of

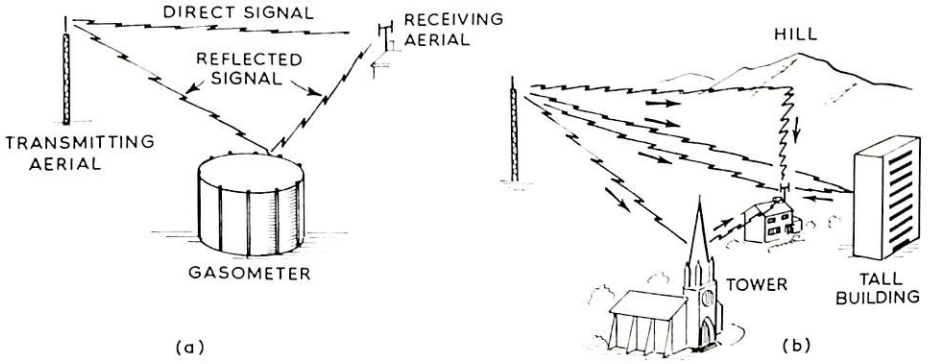


FIG. 1.15. *Multipath interference resulting from signal reflections. At* (a) *the receiving aerial picks up two signals, the direct signal and the signal reflected by the gasometer. At* (b) *the reflecting conditions are more complicated. Here are three reflecting objects, a large hill, a tall building and a tower. The receiving aerial thus responds to four signals, the direct and three reflected signals. Normally, a directional aerial would be used to provide maximum discrimination against the unwanted signal.*

300,000,000 metres/second. This is almost equal to 186,000 miles/second. So in a millionth of a second (a microsecond or μS) radio waves travel a distance of 0·186 miles. Hence, the 1 in. displacement on this 625-line set represents an extra distance of a little under 1 mile (0·186 × 5·3).

On a 405-line set the active line scan takes about 80 μS, so with this standard and the above-mentioned factors the extra distance travelled by the reflected wave would be 0·186 × 8, or a little under 1·5 miles.

Fig. 1.15 (*b*) shows a much more complicated multipath interference condition. Here we have three reflecting objects, a hill, a tall building and a tower. The receiving aerial in this case would receive four signals, the direct signal and the three reflected signals. This could result in almost impossible reception.

On v.h.f./f.m. sound channels, multipath reception and signal reflections produce distortion similar to that of a faulty loudspeaker. On colour television receivers, the phase distortion that can result from multipath interference could make reception in such areas extremely difficult, and often impossible.

As already intimated, a reflected signal can arrive at the receiving aerial either in phase or out of phase with the direct signal; or somewhere between the in and out of phase conditions. If the two signals are in phase they add together, if they are out of phase they subtract one from the other. If they are completely antiphase and of equal amplitude, there is cancellation of signal at the aerial.

These effects are vividly demonstrated by the reflected signals from a passing aircraft, for in addition to ghosting, the signal strength applied to a television set is seen to rise and fall sometimes to zero as the aircraft passes through its reflecting peak. If a signal strength meter is connected to the end of the aerial downlead, the violent oscillation of the meter's pointer tells the same story. To minimize "aircraft flutter", as the above disturbance is often termed, the transmitting aerials of television stations are designed to concentrate the signals to a fairly low angle. Sky waves are no good for consistent reception at v.h.f. and u.h.f. as they are mostly lost in space. The aerials are sometimes directional to beam the signals to certain areas.

In addition to abstracting as much signal energy from a radio wave as possible, it is also the job of the aerial to afford the greatest possible discrimination against interfering signals of all kinds. This is accomplished by designing the aerials to be directional, a subject which is covered in Chapter 2. At this time, however, we should briefly consider interfering signals themselves, since they have much in common with the wanted radio waves.

TYPES OF INTERFERENCE

There are four main kinds of radio interference. They are the kind that affects television pictures due to shared channel working (*co-channel*

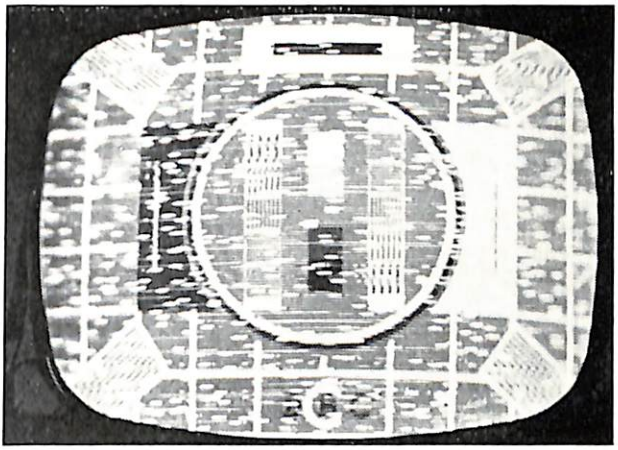
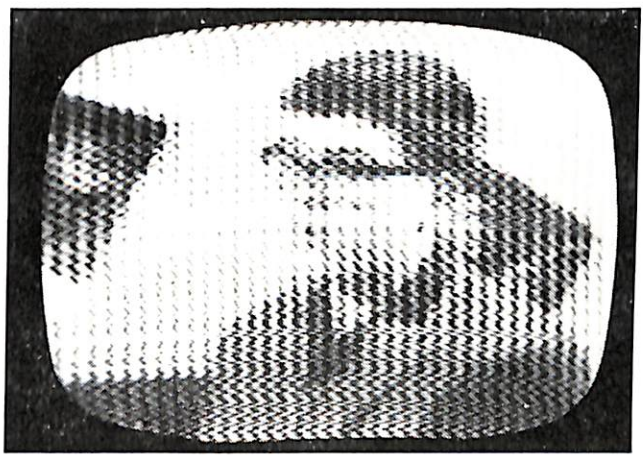


FIG. 1.16. *Television interference effects.* (a) *Impulsive interference which is caused by electrical sparking, such as from the spark plugs of car engines, the contacts of electrical switches and the brushes of electric motors.*



(b) *An example of r.f. interference. This results when the set receives the wanted signal plus an unwanted r.f. signal at a frequency fairly close to that of the wanted signal. A third, interfering signal is then created.*

interference), the kind that gives white spots on a television picture and crackles on sound (*impulsive interference*), the type that gives pattern effects on a television picture and whistles on sound (*r.f. interference*) and the type which is caused by the receiver responding to signals originating from outer space or other natural causes (*atmospheric interference*). Co-channel interference is shown in Fig. 1.12, while impulsive interference and r.f. interference are shown in Fig. 1.16 at (*a*) and (*b*) respectively.

All interfering signals have the characteristics of electromagnetic radio waves. This is, indeed, why they are picked up by the receiving equipment, the set itself being unable to tell the difference between the wanted signals and the unwanted interfering signals. The essential difference, of course, between wanted signals and interference is that the former carries useful information while the latter carries random modulation which means nothing

at all in the majority of cases. If the interfering signals themselves do, in fact, carry information, then an interference effect is created by their interaction with the wanted signals.

We have already seen that co-channel interference results from the interaction of two signals both carrying useful information. R.f. interference is of a similar nature. Here, again, we have two signals which "beat" together and produce a third, interfering signal, causing patterns on the screen and whistles on sound.

Multipath interference (ghosting), considered earlier, is also a function of two signals, but this is essentially a propagation interference, rather than the more real kind of interferences now being discussed.

Impulsive interference is caused by a signal created by an electrical discharge, resulting in an electric spark. Such signals are produced, for instance, by the ignition systems of motor cars and internal combustion engines (electric sparks here being developed across the electrodes of the sparking plugs), by sparking across the contacts of electric switches and between the brushes and commutator of electric motors and by electric arc welding equipment and the like.

The "signals" generated by an electric spark arise because of the initial rise in current in the circuit and the oscillatory effect thereafter. The signals so produced are not "continuous" as are those produced by an oscillator. They are sometimes called "damped waves" because of their gradual decay after the initial peak, as shown in Fig. 1.17.

Certain atmospheric interference effects result from impulsive interference, typical in this respect being the "crash" on sound and the flash on vision due to lightning discharges. Other "atmospheric disturbances" have their origin in outer space, in the ionosphere (aurora borealis) and on the stars and the sun. A diversity of signals enter the earth's atmosphere from such far distant places, but fortunately—so far as ordinary radio and television reception is concerned—they do not detract very much from communications. Magnetic storms and severe sun-spot activity, however, may cause a "radio blackout" affecting reception for a short while.

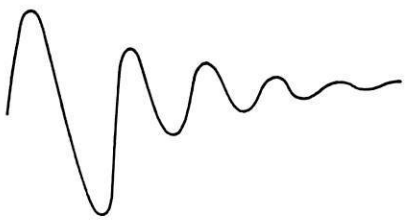


FIG. 1.17. *Representation of a damped oscillation, such as is produced by an electrical spark or discharge.*

Atmospherics and outer space interference can, though, severely disturb earth-to-satellite and satellite-to-earth communications. Noise signals are equally as troublesome as external interference effects, since they put a limit on the "usable sensitivity" of the receiving equipment.

NOISE SIGNALS

Noise signals are generated both in the aerial itself and in the signal amplifying stages of the receiver. Although noise signals result in interference effects, interference as such is generally classified as occurring actually outside the sphere of the receiving equipment and being picked up by the receiving aerial. Noise, on the other hand, is a function of the workings of the receiver and aerial.

Noise has been one of the biggest bugbears of engineers since radio began, and considerable research has been undertaken to minimize it. Noise signals are caused by the random fluctuations in the motion of electrons, and in the distribution of electric and magnetic fields. In space communications, where the signals arriving at the aerial are so small that they would be completely masked by noise signals of ordinary levels, amplifiers operating in a liquid gas are used. As the temperature of a conducting medium is taken down to very low levels, so the random movement of electrons in the circuits becomes less, and the noise signals are reduced in amplitude.

Noise, then, is the random movement of electrons in all electrical conductors, and since a movement of electrons constitutes a flow of electric current, noise currents are present in all conductors and noise voltages are developed across them.

Noise signals in a sound receiver produce a "hiss" from the loudspeaker, rather like the sizzle of car tyres on a wet road. On a television screen they manifest as very small dots of light or shade, sometimes termed "snow-storm" effect on 405-line pictures. They, in effect, put a grain on the picture, particularly if the aerial signal is so weak that the noise signals approach its amplitude, and thus detract from the picture quality and definition. By amplifying the very weak noise signals they can be displayed on the screen of an oscilloscope.

SIGNAL RATIOS

Neither interference nor noise is particularly troublesome when its amplitude is many times below that of the aerial signal. Thus, by keeping the aerial signal as high as possible, the effects of both interference and noise are reduced. This gives rise to two ratios, the signal-to-interference ratio and the signal-to-noise ratio.

Signal/Interference Ratio. This ratio is greatly influenced by the field strength of the wanted and unwanted signals at the receiving site. There are various Post Office stipulations governing the levels of interference that a piece of equipment or plant may legally radiate. It is also compulsory for motorists and users of electrical equipment to minimize any interference emission by means of suppressors.

Unfortunately, it is impossible to rid the ether of all interfering signals. Even the best suppressors cannot be expected to delete all traces of electromagnetic radiation. Nevertheless, suppression of a practical nature ensures that a *correctly installed* radio or television receiver will not greatly suffer from the effects of interference when employed in an area of reasonable signal field strength. Without nearby electrical equipment being so suppressed, the level of interference even under the conditions mentioned could be so high as to make reception difficult. Hence the need for "practical suppression". This, of course, is even more important with the increasing use of domestic electrical equipment and the greater number of cars now on the roads.

In spite of plant, equipment and motor vehicles now being suppressed, each year the Post Office receive a large number of complaints of radio and television interference. In many cases, the trouble is proved to be caused by bad aerial installations. For example, while it may be possible to secure good television reception on a very simple indoor aerial within the service area of the station at a residential location, something more efficient and more discriminating against interference is demanded in a similar signal field on the main road or at an industrial location.

The idea is to obtain the best possible signal/interference ratio by abstracting as much aerial signal as possible from the wanted radio wave while abstracting as little signal as possible from the interfering radio wave. Such discrimination is possible only at the aerial. There is virtually nothing that can be done in the set itself to enhance the signal/interference ratio.

The Decibel. For an interfering signal not to detract from a wanted signal, the wanted signal must be at least 200 times above the unwanted signal. This corresponds to a signal/interference ratio of 200 : 1 or 46 dB. The symbol "dB" stands for "decibel" which is a logarithmic measure of ratio. It corresponds to the manner in which the human senses respond to changes in stimulus. A voltage or current ratio of two times, for instance, can be expressed as 6 dB (—6 dB if the ratio is down). A four times ratio can be expressed as 12 dB, a ten times ratio as 20 dB, a hundred times ratio as 40 dB (hence 46 dB is equal to a ratio of 200 : 1) and so forth.

Mathematically, the number of decibels (N dB) is expressed as:

$$N\ dB = 20 \log_{10} \frac{E1}{E2}$$

where E1 and E2 represent the voltage ratio. For this formula to be valid the impedances (or resistances) across which E1 and E2 are measured must be equal. If the impedances are unequal, then the formula becomes:

$$N\ dB = 20 \log_{10} \frac{E1}{E2} + 10 \log_{10} \frac{Z2}{Z1}$$

where Z1 and Z2 are the impedances across which E1 and E2 are taken.

For *power* ratios, the formula becomes:

$$N\ dB = 10 \log_{10} \frac{P1}{P2}$$

To save working out such arithmetic, decibel tables are available, such a table being given in Table 1.2. It is just as well to become accustomed to working in decibels as the gain, rejection ratios and so on of aerials and the gains and losses in amplifiers and cables are all expressed in decibels.

Signal/Noise Ratio. Similarly, to mask the "hiss" and grain of noise, the signal/noise ratio should be at least 46 dB. The ratio here, however, is affected both by the receiver circuits and by the aerial signal, the ratio being increased either by increasing the aerial signal voltage or by decreasing the noise signal voltage produced by the set.

While it is true that the noise signal (usually called "equivalent noise signal") generated by a receiver is fixed by the design of its circuits, the efficiency of the aerial coupling and the type of valves or transistors used for the early stages, it often happens that the noise signal rises as the receiver ages and the various components reduce in efficiency. This applies more to valve circuits than those using transistors. Gradual misalignment of the circuits can also impair the noise performance.

The equivalent noise signal is that signal input level which would be required to give the noise output at the receiver. As a simple illustration, the equivalent noise signal would be 5 μV if a receiver channel having an overall

Table 1.2

DECIBEL TABLE

Loss		*dB*	*Gain*		*Loss*		*dB*	*Gain*	
Voltage	*Power*		*Voltage*	*Power*	*Voltage*	*Power*		*Voltage*	*Power*
1·0	1·0	0	1·0	1·0	0·5624	0·3162	5·0	1·778	3·162
0·9883	0·9772	0·1	1·012	1·022	0·5307	0·2819	5·5	1·884	3·548
0·9777	0·9551	0·2	1·023	1·047	0·5012	0·2512	6·0	1·995	3·981
0·9661	0·9328	0·3	1·032	1·072	0·4467	0·1995	7·0	2·239	5·012
0·9551	0·9120	0·4	1·047	1·097	0·3981	0·1585	8·0	2·512	6·310
0·9442	0·8914	0·5	1·059	1·122	0·3548	0·1259	9·0	2·818	7·943
0·9328	0·8711	0·6	1·072	1·148	0·3162	0·1000	10	3·162	10·000
0·9223	0·8509	0·7	1·084	1·175	0·2818	0·07943	11	3·549	12·59
0·9120	0·8320	0·8	1·097	1·202	0·2512	0·06310	12	3·981	15·85
0·9023	0·8130	0·9	1·109	1·230	0·2239	0·05012	13	4·467	19·95
0·8914	0·7942	1·0	1·122	1·259	0·1995	0·03981	14	5·012	25·12
0·8711	0·7590	1·2	1·148	1·318	0·1778	0·03162	15	5·623	31·62
0·8505	0·7246	1·4	1·175	1·380	0·1585	0·02512	16	6·310	39·81
0·8320	0·6920	1·6	1·202	1·445	0·1413	0·01995	17	7·079	50·12
0·8130	0·6606	1·8	1·230	1·514	0·1259	0·01585	18	7·943	63·10
0·7942	0·6308	2·0	1·259	1·585	0·1122	0·01259	19	8·913	79·43
0·7762	0·6024	2·2	1·288	1·660	0·1000	0·01000	20	10·000	100·00
0·7590	0·5754	2·4	1·318	1·733	0·056	0·00316	25	17·78	316·2
0·7414	0·5494	2·6	1·349	1·820	0·03162	0·001	30	31·62	1,000
0·7246	0·5247	2·8	1·380	1·905	0·01778	0·000316	35	56·23	3,162
0·7078	0·5012	3·0	1·413	1·995	0·010	0·0001	40	100·0	10,000
0·6682	0·4466	3·5	1·496	2·239	0·0056	0·0000316	45	177·8	31,620
0·6308	0·3981	4·0	1·585	2·512	0·003162	0·00001	50	316·2	100,000
0·5955	0·3549	4·5	1·679	2·818					

gain of 20 dB (ten times) delivered a noise signal of 50 μV amplitude. To push this noise into insignificance, the aerial signal would have to be 200 times (46 dB) above the 5 μV equivalent noise signal. That is, 1,000 μV or 1 mV.

If the aerial signal was only 500 μV, then the signal/noise ratio would be 40 dB (100 times) and there would be traces of "noise" on the picture obtained. An even smaller aerial signal would produce more noise effect, and with a very weak signal the noise would predominate and reception would be very disturbed.

The signal/noise ratio of a receiver can be improved relative to a given aerial signal strength by the use of a low-noise amplifier between the aerial and the receiver, as explained in Chapter 6.

INTERFERENCE AND NOISE SPECTRUM

Owing to its transitory nature, noise has component frequencies which spread over the entire audio and radio spectrum of frequencies. It is thus present in equipment of all types, including television and audio equipment.

Interference, on the other hand, may have most of its energy concentrated in specific portions of the spectrum, depending upon how it is derived. Car ignition interference, for instance, mainly affects reception towards the very top of the h.f. bands and in the v.h.f. bands. The effect starts to tail off towards the top of the v.h.f. bands and is not very troublesome in the u.h.f. bands. This is why television reception on Band I and on the lower channels of Band III is more affected by traffic interference than reception of BBC2 on the u.h.f. channels.

Impulsive interference is not greatly troublesome on the v.h.f. channels of Band II (the f.m. band) because it gives rise to an amplitude modulated component on the radio wave, and frequency modulation receivers should not be responsive to amplitude modulated signals.

Ignition interference is aggravated on the television wavelengths because the sparking plug and coil leads in the ignition system of the car, which carry the oscillatory energy, are comparable in length to a sub-multiple of the wavelength of the signals of television. Thus, the interfering signals are coupled to the ether with a reasonable degree of efficiency. The same does not apply on the longer m.f. wavelengths.

Nevertheless, ignition interference does cause trouble when a m.f. receiver is installed in a car, close to the ignition system, and when such a receiver—or a transistor portable with a ferrite rod aerial—is used close to the main road, particularly when it is receiving a weak programme signal. This is why extra suppression is generally required in a car in which a radio of some kind is used.

Atmospheric interference and static gives most trouble on the longer wavelengths. A distant thunderstorm, for example, can often be picked up

during the summer months by tuning a set to the low-frequency end of the long waveband. Each time a distant flash of lightning occurs a "crash" is heard in the loudspeaker. With a portable set, the approximate direction of the storm can be ascertained by orientating the set for maximum response to the static. (See under "Ferrite Rod Aerials" in Chapter 3.)

R.f. interference affects only those receivers tuned to the frequency of the interference or receivers whose passband accepts the interfering frequencies.

IMPORTANCE OF A GOOD EARTH

The importance of a good aerial has now been expounded, but in certain h.f. and m.f. installations the earth is almost equally as important. In the early days of radio, reception troubles due to inefficiency of installation of aerial and earth were unlikely because m.f. reception then demanded a lofty long-wire aerial and a good earth. The situation today is vastly different. Modern sets are far more sensitive than their vintage counterparts; interference is much more widespread now than it was then; and the medium waveband, in particular, is cramped with transmissions to a degree unheard of a decade or two ago.

Today's high receiver sensitivities tempt one to make do with just the odd bit of wire for the aerial and conveniently forget all about the earth! Of course, portable sets with their ferrite rod aerials are designed for use without external aerial and earth. But we must consider those m.f. and h.f. sets and tuners which feature aerial and earth sockets. V.h.f./f.m. broadcasting solves many reception problems, but there are millions of sets operating still on the m.f. a.m. bands, and while Radio Luxembourg and other popular stations still haunt the m.f. bands, the demand for the m.f. a.m. services will not decline.

The majority of ordinary m.f. aerials are tuned to no specific frequency and they are, therefore, responsive to all signals in the long, medium and short wavebands. Such aerials, however, may work best at one particular frequency—called the aerial's "natural frequency", as explained in Chapter 2.

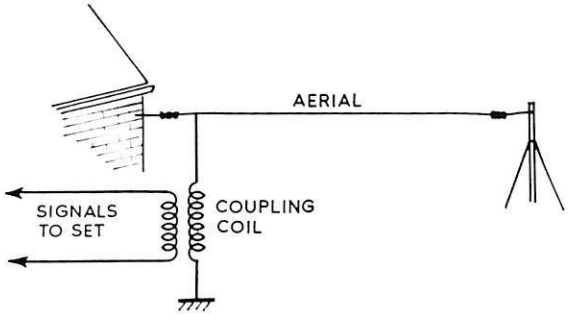


FIG. 1.18. *Aerial coupling arrangement used in m.f. and h.f. receivers. Note the earth completing the tuned coupling circuit.*

The signal induced into a long-wire aerial from a radio wave is relative to the earth. This means that the signals cannot successfully be coupled to the set from the aerial alone; there must also be a good earth connection. Fig. 1.18 shows how the signal is coupled to the set, the set working simply because the required signal is induced across the coupling coil.

Sensitive sets will operate with a short length of wire for the aerial and with no earth. From the signal point of view, however, the set is always earthed to some degree by the capacitance between the chassis and the earth or between the chassis and the mains supply (assuming a mains-operated set). Such indirect earths are very inefficient.

As the strength of the signals fed to the set are proportional to the strength of the signals induced in the coupling coil, it follows that the earth lead itself must have very little loss for maximum signal transfer. If the earth lead is long it acts as an impedance at the bottom of the coupling coil, meaning that a portion of the signal is lost across it. Moreover, a long earth lead may itself pick up some signal, as an aerial, and thus cancel out some of the signal that the aerial proper has picked up! As the earth lead is usually fairly low down, it can pick up electrical interference and convey it into the set if it is abnormally long. It is important, therefore, for the earth to be as efficient as possible and to be connected to the set through stout copper wire of the shortest possible length.

CHAPTER 2

Principles of Aerials and Feeders

THE primary duty of a receiving aerial is to abstract as much signal power as possible from the required radio wave. Some aerials are required to work at high efficiency over a relatively wide range of frequencies; others are designed essentially to respond over a relatively narrow band of frequencies. The latter type is used with television sets and the former with ordinary a.m. broadcast radio sets. A broadcast aerial is expected to pick up signals adequately in the long, medium and short wave bands, whereas the television receiving aerial will normally be designed to respond just to one channel or group of channels.

Generally speaking, an aerial designed for a specific frequency or a narrow band of frequencies is more efficient than an aerial designed to work over a wide frequency spectrum. This must not be taken to mean, however, that "wide-band" aerials are singularly inefficient, as much depends on the signal frequencies and the exact design of the aerial system. Television aerials can be designed to have a relatively high efficiency over several channels, or up to 100 MHz in the u.h.f. bands, where the wavelength is short. Indeed, it is necessary for a u.h.f. television aerial to have a bandwidth of at least 88 MHz to embrace the four u.h.f. channels in a local group. The bandwidth requirement may even be in excess of this, in areas where the group of four channels extends beyond 88 MHz.

When considering aerials it is often easier to examine them in terms of transmitting aerials or radiators, rather than receptors, since it is axiomatic that a good "radiator" must be a good "receptor".

Let us, then, examine the effects that would result from the connection of a wire of infinite length to a signal source. Such an arrangement is shown in Fig. 2.1 (*a*). The signal fed to the infinitely long wire is of a sine wave characteristic. This means that it passes from a positive voltage maximum, through zero to a negative maximum and back again in time, as determined by the frequency of the signal. The voltage applied will produce a current wave in the conductor or wire, and this wave will have exactly the same characteristics as the signal voltage, shown by the broken-line sine wave in Fig. 2.1 (*b*). This current wave does not occur instantaneously all along the

wire. It travels along the wire, and since the wire is of a hypothetically infinite length, the wave will never arrive at the termination!

Now, the changing amplitude of current along the wire produces a partnering voltage wave. The voltage wave is also of a sine wave characteristic, the maximum amplitude of voltage occurring at points along the wire where the *rate of change* of the current wave is greatest. The voltage wave is shown by the full-line curve in Fig. 2.1 (*b*). From this it will be seen that the current wave leads the voltage wave by 90 deg.

These waves go on travelling the length of the wire to infinity at a speed which is something less than the speed of radio waves in free-space, because the wire tends to slow down the waves. The amplitude of the waves will gradually reduce, of course, due to losses.

It must at this stage be understood that the infinitely long wire—or, indeed, any wire—has distributed capacitances along its length to earth. The wire itself is also inductive. Thus, the voltage and current waves are with respect to earth. A wire of this nature could be considered as a simple "waveguide".

Because the waves along the wire are electric (the voltage wave) and magnetic (the current wave) partners, signal energy is liberated into the ether. Radio waves are thus released, and because these are themselves composed of electromagnetic components they are self-sustained, and are propagated into space at the speed of light, as we saw in Chapter 1. The wire is, therefore, a radiator of electromagnetic energy, i.e. a transmitting aerial.

Reciprocally, such a wire would equally as well abstract signal energy from the ether. Voltage and current waves would also in this application occur along its length, and in this case a receiver would be connected at

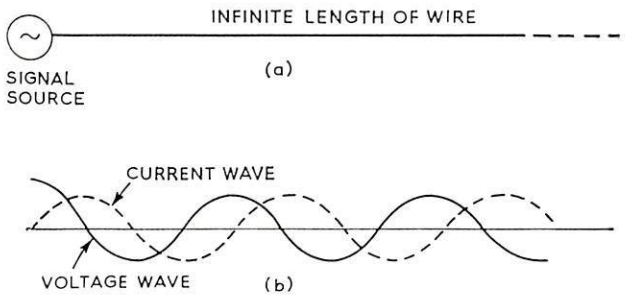


FIG. 2.1. *The application of a signal source to an infinitely long wire* (a) *produces voltage and current waves as shown at* (b). *The amplitude of these waves gradually diminishes due to radiation and conductor losses. The discontinuity due to a practical wire of finite length so energized causes wave reflections back up the wire unless the wire is "loaded" by a resistance, the purpose of which is to absorb the signal energy at the end of the wire.*

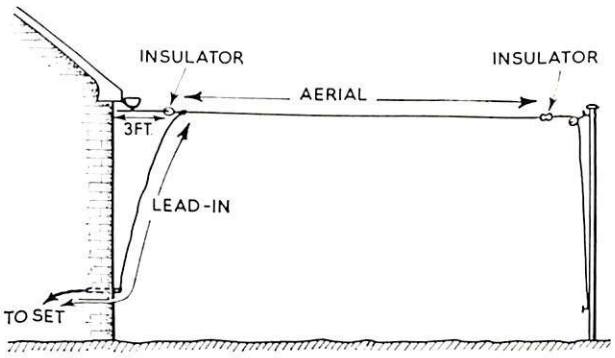


FIG. 2.2. *A typical long-wire aerial, sometimes called an "inverted L" aerial. The whole length of wire serves to pick up signals, including the lead-in and lead to the set.*

the start of the wire in place of the signal source. The signal abstracted from the ether would produce a small signal voltage across the aerial load of the set.

LONG-WIRE AERIAL

The nearest approach to an aerial of infinite length is the so-called "long-wire" aerial. This may be of such a length as to accommodate a number of complete wavelengths of the signal, or the wavelength of the signal may be considerably greater than the length of the aerial.

Long-wire aerials are often used with a.m. broadcast receivers. In the early days of radio, when the crystal set was in vogue, they were essential to collect m.f. signals of adequate amplitude to work a crystal set, since this kind of set relies on the actual voltage produced by the signal to work the headphones. It was often found that the longer the aerial wire, the stronger the reception. This was because the closer the length of the aerial came to the signal half-wavelength, the greater the signal pickup.

Clearly, a long-wire broadcast aerial of practical length would be only a fraction of a half-wavelength relative to signals in the long and medium wave bands. On the other hand, the same aerial may represent a number of complete half-wavelengths to signals in the short wave bands. All this boils down to the fact that the long-wire aerial is essentially "untuned". Of course, any aerial must tune to some specific frequency or wavelength, since it possesses both distributed inductance and capacitance. The lowest frequency of free oscillation is termed the aerial's "natural frequency".

Similarly, the aerial must have a natural wavelength. As a rough guide, this can be taken to be approximately equal to $4\frac{1}{2}$ times its electrical length—that is, its length between the insulators, plus the length of the lead-in, as revealed in Fig. 2.2. An aerial having an electrical length of 100 ft has a natural wavelength of about 120 metres, and transmissions around this wavelength would be received by the connection of a 100 ft aerial to an untuned detector.

Incidentally, it is interesting to note that the maximum length of an aerial permitted by the Post Office is 150 ft.

Now let us consider a long-wire aerial of finite length as a radiator. We will assume that the wire is sufficiently long to accommodate a number of complete wavelengths of the signal. The application of signal to such a wire means that some of the signal energy will reach the far end. Now, if this end is open-circuit there is discontinuity of signal path. Such a condition causes the waves to be reflected back along the wire. Thus, we have waves travelling from the signal source towards the end, and reflected waves travelling back from the end towards the signal source. The reflected waves produce fields in opposition to those of the forward travelling waves, and a cancellation effect results, thereby reducing the efficiency of the wire as a radiator and, reciprocally, as a receiving aerial.

This inherent inefficiency can be countered by terminating the end of the wire with a resistance equal in value to the "characteristic impedance" of the wire at the end. All the signal energy then arriving at the end of the wire is absorbed by the resistance and prevented from being reflected back up the wire.

All this means that the shorter an untuned aerial, the smaller its efficiency. However, even a very short length of wire will act as a radiator and as a receptor to some extent, which is the reason why just the odd length of wire pushed into the aerial socket of a modern set will give some sort of reception. The efficiency under this condition is, of course, extremely poor, and reception is possible only because modern sets are so very sensitive. The price that is paid for poor aerial efficiency is not only lack of response to weak signals but also poor signal/noise and signal/interference ratios.

In Chapter 1 we saw how the first stage of a receiver or r.f. amplifier can be considered as having fed to it an equivalent noise signal in addition to the required signal and interference signals picked up by the aerial. A poor aerial will naturally produce a weaker signal voltage than a more efficient aerial, causing impairment of the signal/noise ratio. In addition, external interference may cause a greater interference voltage across a poor aerial than across one which is more efficient and discriminating against interference, thereby impairing the signal/interference ratio.

The odd piece of wire serving as the aerial may well be in a heavy interference field, so even though the set may be sensitive enough to respond to the weak wanted signal picked up by such a piece of wire, the local interference may well outweigh the wanted signal, thereby making reception almost impossible or very crackly, to say the least.

Many modern a.m. broadcast sets and tuners incorporate an inbuilt ferrite rod aerial, about which more will be said later. Sets without this fitment deserve a reasonable external aerial (and earth—see Chapter 1). For really

serious a.m. reception, an aerial of the nature of that depicted in Fig. 2.2 is desirable; unfortunately, such elaborate aerials are rarely employed nowadays.

SIMPLE INDOOR M.F. AERIALS

In an area of low local interference, a simple attic or indoor aerial of about 25 ft in total length may suffice. The wire can be spread out beneath the carpet or fixed round the picture rail or skirting board. With a fair earth (often picked up from the earth terminal of the three-pronged plug supplying the set with mains power), good reception of the popular long and medium stations is possible. For short wave reception a more efficient arrangement is desirable.

Stranded copper wire with a coloured, plastic insulation is ideal for simple indoor aerials, and those fixed in the attic or roof space should be supported by insulators between two beams so that the aerial can be run almost the whole length of the roof. The downlead (as in Fig. 2.2) can be tacked along a joist and fed to the set either through a small hole where the ceiling meets the wall or it can be taken out through a tile or slate near the guttering, tacked down the outside wall and brought to the set through the window frame. Both the aerial proper and the downlead should be kept well clear of electric cables, since these pick up and re-radiate interfering signals. It should be remembered that the downlead of this type of aerial itself acts as a part of the aerial and picks up signals.

In areas of very high local interference, it may be necessary to site the aerial away from the zone of maximum interference and then convey the signal to the set through a screened downlead which does not pick up signals.

An untuned aerial of the type that is being considered has a relatively high impedance at the set end. The set aerial input circuit is thus designed to possess a matching high impedance. Now, screened cable, such as coaxial cable, has a low impedance, so if this is connected direct to the aerial at one end and to the set at the other, and the screen is earthed (as it must be for maximum interference suppression), a large amount of signal voltage would be lost.

ANTI-INTERFERENCE AERIAL SYSTEM

In practice, this can be overcome by the use of two matching transformers, one either end of the screened cable. The transformer at the aerial end of the cable transforms the high impedance of the aerial to the low impedance of the cable, while that at the set end of the cable transforms the low impedance of the cable to the high impedance of the aerial input circuit of the set.

The idea is shown in Fig. 2.3. Here the aerial is located outside the

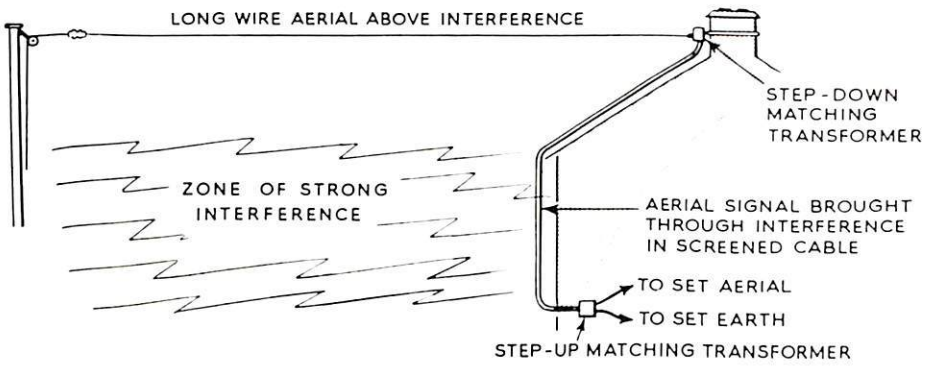


FIG. 2.3. *A long-wire anti-interference broadcast receiving aerial. This is positioned high above the interference field and the aerial signal is conveyed to the set through screened cable. Transformers are used at either end of the screened cable for matching purposes, as explained in the text.*

interference field and the signal is brought through the interference under the protection of screened cable. An alternative arrangement is the use of a rod-type aerial in place of the long-wire variety. The matching transformer in this case is located at the bottom of the rod, and with some proprietary brands of "anti-interference" m.f. aerial systems the matching transformer itself acts as the insulator for supporting the aerial to chimney-stack corner brackets or clamps. This arrangement is shown in Fig. 2.4.

The definition of an anti-interference aerial system is an aerial designed to discriminate against the reception of locally generated r.f. noise (i.e., interference).

In the past, many variations of untuned m.f. aerials have been adopted, each claimed to possess certain desirable characteristics from the reception point of view. Those days, however, have now passed and the aerial of today is the "tuned" or resonant aerial. The resonant aerial is suitable essentially for the reception of signals in the h.f. (short wave), v.h.f. and u.h.f. bands. It is used at even higher frequencies, which do not concern us here, and, of course, it is equally as suitable for transmitting as for receiving.

The length of a resonant aerial is related to the wavelength of the signal it is required to tune, and for this reason a resonant aerial is not a feasible proposition for the reception of signals in the long and medium wave bands. To tune over these bands its length would be excessive from the domestic point of view, as we shall see.

Resonant aerials are designed so that the distributed inductance over their length and the distributed capacitance between the two halves tune to the required wavelength or frequency. From this aspect, therefore, the resonant aerial can be considered analogous to a tuned circuit.

An aerial is said to be tuned when its overall length is almost equal to a half-wavelength of the signal. Let us consider a conductor whose length is such that it just accommodates one complete wave of signal current, as shown in Fig. 2.5. It will be recalled that a current wave of this nature is induced into the conductor from the passing radio wave.

Now, if the wavelength of the signal is, say, 10 metres, we may expect the overall length of the aerial conductor to be of a like value. This is not exactly correct, however, because a radio wave does not travel at quite the same speed along a conductor as it does in free space. The conductor slows down the wave very slightly. This means that the conductor will have to be a little shorter than the wavelength of the signal to get the complete wave to fit exactly.

HALF-WAVE AERIAL

Fig. 2.5 shows that wave section A-B is identical to wave section B-C but of opposite sign. A complete change of current, from zero to maximum and back to zero again, is thus accommodated in a conductor whose length is half

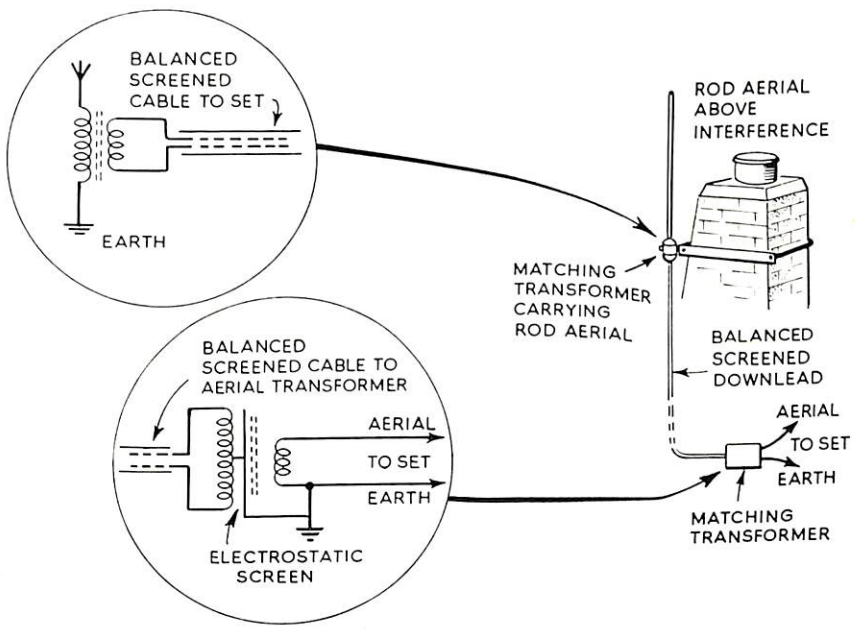


FIG. 2.4. *This kind of anti-interference aerial employs a rod instead of a long wire. For matching to the screened downlead, an impedance step-up transformer is used at the set end and an impedance step-down transformer at the aerial end. These transformers need to have a flat frequency characteristic over the band to be tuned. The latest ferrite cores facilitate the design of this kind of transformer.*

that of a full-wave conductor. Here, then, is our half-wave aerial. It is nothing more complicated than a conductor whose length is a little less than half the wavelength of the signal it is required to tune. Actually, the physical length of a half-wave aerial is approximately 95 per cent of half the wavelength of the signal.

Say the signal frequency is 150 MHz. The wavelength is thus 300/150, which works out to 2 metres. Half of this is 1 metre, and 95 per cent of 1 metre is 0·95 metre, which would be the length of a half-wave aerial to tune 150 MHz.

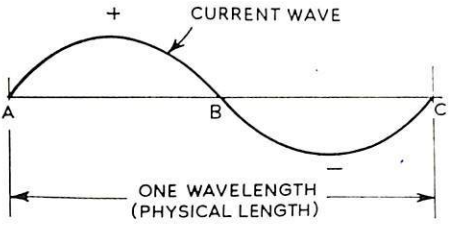
If we want to work in feet, then we must multiply the length in metres by 3·281 (or by 39·37 to bring metres to inches). In the above example, this works out to 3·117 ft. The length of a half-wave aerial in feet can also be found simply by dividing 468 by the frequency of the signal in MHz. This gives 3·12 ft in the above example, which is very close to that calculated the long way round.

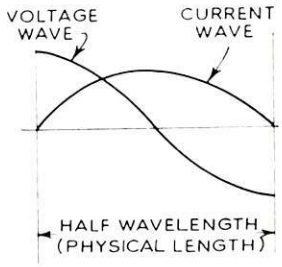
Fig. 2.6 shows the current wave in a half-wave aerial and also the voltage wave that the current wave produces. The voltage wave is at maximum amplitude when the rate of change of the current wave is at maximum.

It is also possible to get a quarter-wave aerial to work by using either the earth proper or an artificial earth to produce an "image" of the missing quarter-wave section. A quarter-wave aerial is sometimes referred to as an "image aerial". The combined action of a quarter-wave aerial and its image is the same as that of a true half-wave aerial, as shown in Fig. 2.7.

Conductors of lengths equal to multiples of quarter- or half-waves of the signal frequency can also be considered as tuned or resonant aerials, but the shortest self-resonant length is the half-wave aerial.

Half-wave aerials form the basis of all f.m. radio and television aerials, while quarter-wave aerials are often used for point-to-point v.h.f. and u.h.f. mobile communications systems. When this kind of aerial is fitted to a





(Left) FIG. 2.5. *The current wave induced by a radio wave into a conductor whose length is 5 per cent shorter than the signal wavelength.* (Right) FIG. 2.6. *Since a conductor half the length of that in* FIG. 2.5 *accommodates a complete current change, from zero to maximum and back again to zero, this represents the shortest conductor that is self-resonant.*

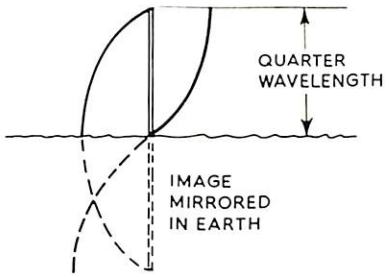


FIG. 2.7. *A quarter-wave aerial uses the earth proper or an artificial earth to "mirror" the missing quarter-wavelength.*

motor vehicle, the metal body provides the "earth" and gives the image effect.

We must now consider how signal energy is fed to or extracted from a resonant aerial. Signal energy is generally said to be fed to a transmitting aerial through a "feeder". The term "lead-in" or "downlead" is more appropriate for the conducting system which conveys signal from an aerial to a receiver. Nevertheless, the term "feeder" is also used in this application.

Fig. 2.6 shows that the current wave is at maximum amplitude at the centre of a half-wave aerial, while at the same point the voltage wave is at minimum (zero) amplitude. At each end the current wave is at minimum amplitude and the voltage wave is at maximum amplitude.

Points where the voltage or current is at minimum amplitude are called voltage or current nodes while points where the voltage or current is at maximum amplitude are called voltage or current anti-nodes. Thus, in Fig. 2.6 there is a voltage anti-node and a current node at each end of the aerial and a current anti-node and a voltage node at the centre.

These conditions remain as long as the aerial is tuned to the signal and the signal continues or, conversely, as long as signal energy is being fed to the aerial at a frequency equal to that to which it is tuned.

AERIAL IMPEDANCE

Since there are components of both current and voltage of varying amplitude and displaced in phase by 90 deg. along a tuned aerial, it follows that a half-wave aerial tuned to a signal has an impedance value along its length that changes from a high value at one end to a low value at the centre, rising again to a high value at the other end.

The condition associated with a low impedance is where the current is high and the voltage low, while that associated with a high impedance is where the voltage is high and the current low—at the centre and ends respectively. Intermediate positions from the centre towards the ends of the aerial represent intermediate values of impedance. Actually, the impedance at the centre of a half-wave aerial is of the order of 72 ohms, and ideally the end impedance should be infinity. In practice, it is of the order of 2,500 ohms.

Now, how is the feeder or downlead connected to the aerial? There are several ways of achieving this connection, but the major factor that has to be satisfied is one of matching. Matching in this context implies that at

the point of connection, the impedance of the feeder or downlead has to equal that of the impedance of the aerial. When this condition exists maximum transfer of signal occurs from the aerial to the downlead or from the feeder to the aerial. If this condition is not satisfied, then losses occur, resulting from the "mismatch". A downlead or feeder itself has a characteristic impedance (usually given the symbol Z_0). We must now learn a little about this.

FEEDERS AND DOWNLEADS

A feeder or downlead of the nature that we are considering serves to guide radio waves fundamentally by a pair of conductors. Indeed, the simplest form of feeder is nothing more than two conductors run in parallel with constant spacing between them along their length. A practical construction takes the form of two conductors embedded in a flat extruded ribbon of low-loss material, such as polythene. A cross-section of such a feeder is shown in Fig. 2.8 (*a*). The cross-section of a slightly different version is given in Fig. 2.8 (*b*).

Such a feeder or downlead possesses not only pure d.c. resistance, but also impedance. This latter component arises from the inductance of the conductors and the capacitance between them. Thus, the terminal impedance of an infinitely long feeder of uniform construction is of some definite value of Z_0 equal to $\sqrt{(L/C)}$, where C is the capacitance of the feeder in farads per unit length and L is the self-inductance of the feeder in henries per unit length. Z_0 is primarily a pure resistance at r.f. Of course, in practice, the finite length of the feeder has to be considered, and Z_0 is still resistive provided the far end of the feeder is terminated in a resistance equal to Z_0.

Waves then travel along the feeder, in the same way as they travel along a long-wire—see Fig. 2.1 (*b*). Discontinuity at the end of a feeder of finite length results in the signal being reflected back again towards the source with consequent cancellation effects. Such discontinuity is avoided, of course, when the far end is properly terminated. Signal energy is then absorbed by the terminating load and signal reflection is prevented. Reflections also occur due to discontinuity or change in characteristics along the feeder, and it is for this reason that feeder should be handled and installed with care, avoiding twisting, kinking, indenting, sharp bends, etc.

FIG. 2.8. *Two types of twin feeder.*

This form of "transmission line" (another name for feeder) is of the twin conductor or "balanced" variety. Sometimes the two conductors are held consistently apart by special, low-loss spacers, giving the ladder appearance

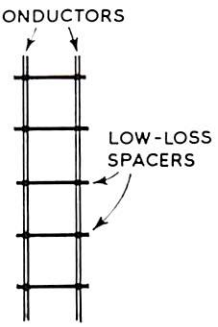
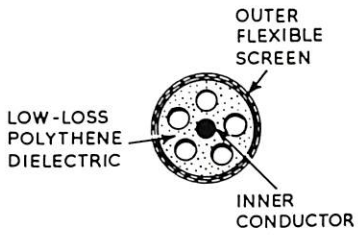


FIG. 2.9. *An open-type balanced feeder, which is usually of* 600 *ohms impedance.* (Right) FIG. 2.10. *Cross-section of coaxial feeder.*



shown in Fig. 2.9. The two conductors are then separated essentially by air instead of by the dielectric supporting medium.

The characteristic impedance, being a function of inductance and capacitance, is determined by the diameter of the conductors and by their spacing. The infinitely long wire in Fig. 2.1, incidentally, can also be considered as a transmission line, the factors concerned here being the diameter of the conductor and the distance between the conductor and earth.

COAXIAL CABLE

Another form of feeder consists of a single conductor enclosed concentrically in a metallic outer cover, often made of a fine copper wire braid to give flexibility. The inner conductor is held concentric along the length of the feeder by means of a low-loss, polythene dielectric or spiral spacer, as shown in Fig. 2.10. This kind of feeder is "unbalanced", as distinct from the balanced "twin feeder" previously described. The Z_0 of coaxial feeder is a function of the inner diameter of the outer conductor and the diameter of the inner conductor.

Clearly, feeders can be "tailored" to possess almost any value of Z_0, but values in common use range from about 50 ohms up to 600 ohms. Resonant receiving aerials are generally used with 70/80 ohm coaxial feeder in Great Britain, while in some other countries 300 ohm twin feeder is favoured. Twin feeder is also available at around 70 ohms impedance encased in a flexible braid screening.

Another very important characteristic of a feeder is its attenuation factor. This is basically a measure of how much the amplitude of a signal applied to one end of a given length of feeder is reduced at the other end. It is usually expressed in decibels per 100 feet at a given frequency, on the assumption that both ends of the feeder are correctly terminated (matched). Mismatching increases the apparent attenuation factor owing to signal cancellation effects resulting from reflections, as already mentioned.

The attenuation factor is influenced by such things as diameter of the conductors and losses in the dielectric. For the lowest losses, the resistance

of the conductors is made small by large diameter while the dielectric is either essentially air (as with open balanced feeders) or a specially designed low-loss polythene material.

The attenuation factor of balanced feeders can be affected by the feeder being in close proximity to conductive objects. It can also be affected by moisture. This can be countered by an outer screen or braid, but then the attenuation factor of the cable usually rises above that associated with a similar cable without the screen. Dielectric losses in coaxial cable are minimized by the use of specially constructed cellular or semi-airspaced polythene. Relatively large diameter inner conductors, or the use of several thinner conductors stranded together to form the inner conductor, reduce resistive losses.

Attenuation rises with increase in signal frequency. A graph showing this effect is given in Fig. 2.11. This relates to television downlead cables of the B.I.C.C. (British Insulated Callender's Cables) range. Table 2.1 gives other features of the cables to which the graph refers.

Still another characteristic of feeders is the "velocity ratio". This reveals to what extent the signal is reduced in velocity from its nominal velocity of light in free space, when it travels down the feeder. This ratio is usually given in terms of a percentage.

When a feeder is incorrectly terminated or open- or short-circuited at one end, the signal reflections that are produced give rise to so-called "standing waves" along the feeder. When this condition exists the effective impedance of the cable departs from Z_0 and then depends on the manner in

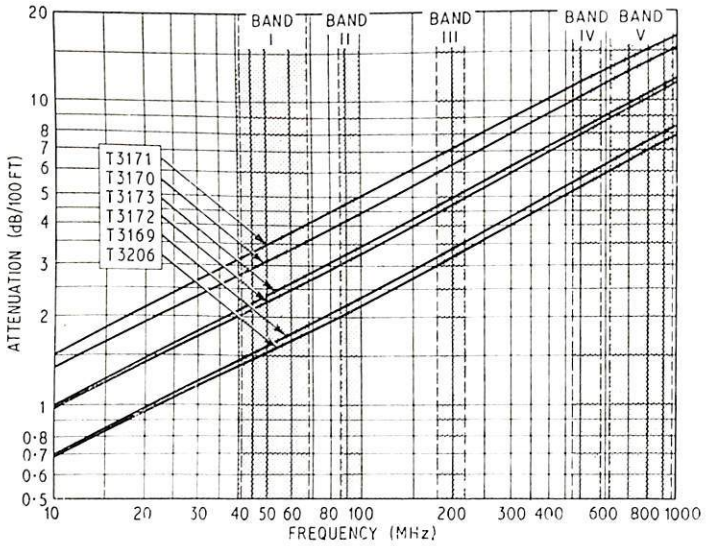


FIG. 2.11. *Graph showing how the attenuation of feeding rises with frequency.*

Table 2.1

DIMENSIONS OF B.I.C.C. TELEVISION DOWNLEAD CABLES

List No.	*Inner Conductor (inch)*	*Nominal Diameter Over Dielectric (inch)*	*Nominal Overall Diameter (inch)*	*Form of Polythene Dielectric*
T3169*	1/·044	0·2	0·284	Cellular
T3206*	1/·048	0·2	0·284	Semi-airspaced
T3172	1/·029	0·128	0·202	Cellular
T3173*	7/·010	0·128	0·202	Cellular
T3170†	1/·022	0·093	0·157	Cellular
T3171†	7/·0076	0·093	0·157	Cellular
T3066*‡	1/·036	—	0·16 × 0·10	Solid

* *In accordance with B.S.3040:1958* † *Recommended for indoor and loft aerials*
‡ *Unscreened twin. Conductor centres spaced 0·050 inch nominal. Attenuation values as for T3170 up to 200 MHz*

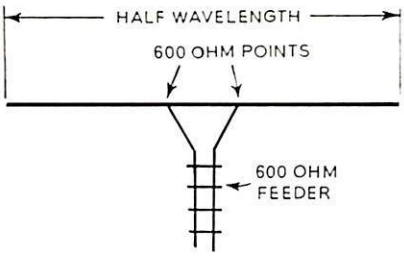
which the reflected waves interfere with the forward waves. The effective impedance depends on the length of the feeder, changing from a low value to a high value through every quarter-wavelength.

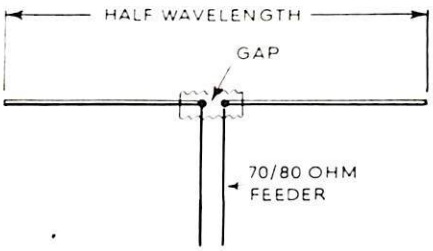
STANDING WAVE RATIO

The ratio of voltage (or current) in the reflected wave to that in the forward wave is called the "reflection coefficient", while the ratio of the maximum to the minimum voltage (or current) that appears at points along the cable is called the "standing wave ratio" (s.w.r.). The term "voltage standing wave ratio" (v.s.w.r.) is more frequently used. As we now know, the distance between a maximum and an adjacent minimum is one quarter-wavelength.

From what we have learnt about the impedance of resonant aerials and the impedance of feeders, obvious ways of connecting one to the other without inciting a mismatch become apparent. Suppose, for example, that we wish to "feed" a half-wave aerial from 600 ohm feeder. All we should do would be to find the points either side of the centre of the conductor corresponding to 600 ohms and then connect the feeder to these, as shown in Fig. 2.12. A perfect impedance match would then be achieved and maximum transfer of signal would occur either from the feeder to the aerial (when transmitting) or from the aerial to the feeder (when receiving).

Note that the difference between the width of the feeder (i.e., the distance between the two conductors) and the distance between the two 600 ohm points on the aerial may arise because a practical 600 ohm feeder may not coincide with the 600 ohm points, depending on the wavelength to which the aerial is cut. By far the commonest way of connecting a feeder to a half-wave aerial, however, is to cut it exactly into two halves, support them





(Left) FIG. 2.12. *How* 600 *ohm feeder is connected to the corresponding* 600 *ohm points of a half-wave aerial to obtain correct matching.* (Right) FIG. 2.13. *Half-wave dipole. The half-wave aerial is cut into two halves of equal length and maintained mechanically rigid by means of a centre insulator. The two ends at the insulator are separated by about one-eighth inch, and the impedance across the gap is about* 70 *ohms, thereby facilitating the direct connection of* 70 *ohm feeder.*

mechanically by a centre insulator, leaving a little gap between the ends of the two conductors, and then to couple the feeder across the gap, as shown in Fig. 2.13.

HALF-WAVE DIPOLE

A half-wave aerial so arranged is called a "half-wave dipole", and it forms the basis of most domestic v.h.f. and u.h.f. aerials, as we shall see. Incidentally, the term "dipole" implies an open aerial excited in such a way that the standing wave of current is symmetrical about its midpoint.

When the gap between the two ends of the aerial at the insulator is of the order of $\frac{1}{8}$ in., the impedance is close to 70 ohms, making it a very convenient point at which to connect 70 ohm feeder for optimum matching. Theoretically, a dipole aerial is a balanced device, which means that it should really be connected to balanced feeder. In practice, unbalanced coaxial feeder is often used, particularly in receiving installations. As we have seen, unbalanced coaxial cable is far more robust than twin, balanced feeder and is less influenced by proximity effects.

Nevertheless, there are times when the connection of an unbalanced feeder to a balanced aerial can disturb the basic design characteristics of the aerial, particularly at u.h.f. and when the dipole forms part of a high-gain array. To avoid the use of twin feeder under these circumstances, about which more will be said later, a special transformer (or transforming device) is employed between the dipole and the unbalanced feeder so as to provide a "balanced" effect between the coaxial and the dipole.

The name given to such a transforming device is "balun", derived from balanced-to-unbalanced. A balun is sometimes featured on a u.h.f. television aerial, as we shall see.

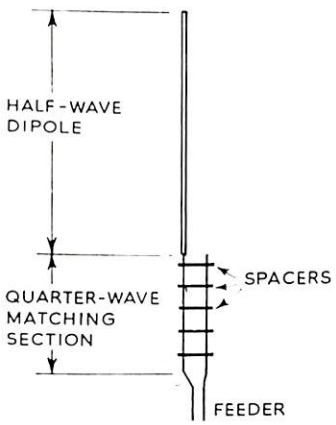
J AERIAL

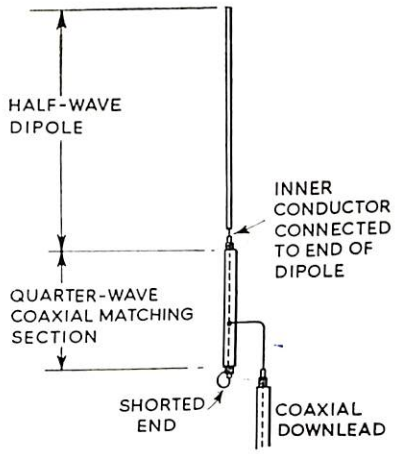
Sometimes a half-wave dipole is fed at one end, where the impedance is high. An aerial with this kind of feeding is called a "J aerial", and matching from low impedance cable (about 70 ohms) to the high end impedance of the dipole is achieved by a quarter-wave section of cable or by a parallel-wire quarter-wave section. The idea is shown in Fig. 2.14. Here, the parallel-wire quarter-wave section acts as an impedance transformer.

The end of the matching section is itself a high impedance and thus matches the high end impedance of the dipole (note that the term "dipole" is used still in spite of the fact that the half-wave aerial of a J aerial is in one piece). The impedance from the aerial end to the feeder end of the matching section gradually falls, and this permits a relatively low impedance feeder to be matched at the far end. The impedance characteristics of a parallel-wire quarter-wave section are governed by the distance between the two parallel wires and by their diameter.

Connection of the section to the aerial and feeder is very simple. At the bottom end the two wires of the section are connected to the two conductors of the feeder, while at the top end one wire is joined to the dipole and the other is left free.

The parallel-wire quarter-wave section is generally used for connection to twin, balanced feeder. However, it is possible to create a J aerial with





(Left) FIG. 2.14. *Quarter-wave parallel-wire matching section to allow the high impedance end of a dipole to be connected to a relatively lower impedance feeder. This arrangement forms the basic "J aerial".* (Right) FIG. 2.15. *A short-circuited quarter-wave section of coaxial feeder can also be used to allow a coaxial feeder to be connected to the high impedance end of a dipole.*

a low impedance coaxial feeder downlead, as shown in Fig. 2.15. Here, instead of a parallel-wire quarter-wave section a quarter-wavelength of coaxial feeder is used.

It will be seen that one end of the coaxial matching section is short-circuited. Now, a characteristic of a shorted quarter-wavelength of coaxial cable is that the impedance at the open end remains very high, and thus represents a very good match to the high impedance end of the dipole, while the impedance at the shorted end is zero. Thus, the impedance from the shorted end rises from zero to a high value at the open end. This means that the downlead coaxial cable can be tapped in at the point along the section corresponding to its own characteristic impedance. In this way perfect matching can be attained and the downlead is held clear of the signal field of the dipole.

This latter aspect is desirable, for if the feeder penetrates the aerial's field too deeply the qualities of the aerial are affected. It is for this reason that the feeder should be brought away from a centre-connected dipole at right-angles for a distance of at least a quarter-wavelength. This is not difficult to achieve when the aerial is mounted horizontally, but problems in this connection can arise when the aerial is vertically disposed.

FOLDED DIPOLE

The centre impedance of a half-wave dipole can be increased from its nominal 70-odd ohm impedance by the simple expedient of folding it while retaining an overall length of half a wavelength, as shown in Fig. 2.16.

The best way of considering the folded dipole is on the basis of r.f.

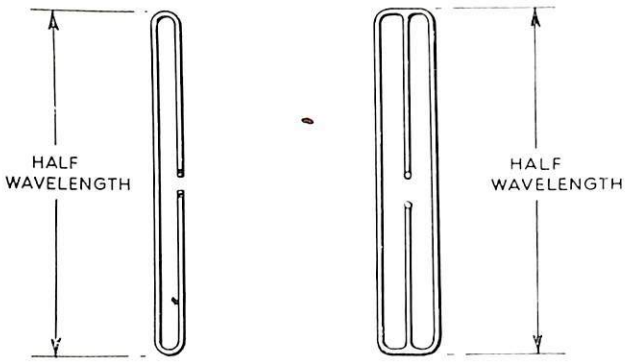


FIG. 2.16. *Folded dipoles.* (Left) *single fold, giving an impedance step-up of four times at the centre;* (right) *double fold, giving an impedance step-up of nine times. The centre of the folded part of the dipole in each case is at the point of maximum current or zero impedance* ("*earth*") *and may thus be directly clamped to the cross-bar carrying the parasitic elements in the case of a practical aerial.*

signal current flowing in an ordinary, single dipole element. Say a signal current of 1 ampere is flowing. Now, when a second element of dimensions equal to that of the energized dipole is brought up very close, a signal current is induced into this also. The effect is that the signal current is divided, half flowing in the energized dipole and the other half flowing in the other dipole. The current and voltage are equally in phase in each dipole. This means that the conditions are unaltered by joining the tops and bottoms of the two dipoles, as in the single fold.

Because the available signal current is divided, the impedance at the centre of the energized dipole is increased by a factor of four times. The impedance in the case of a double fold is increased by nine times, since here the available signal current is divided by three. The square factor gets in because the power is proportional to the square of the current.

Let us suppose that a single dipole has a centre impedance of 75 ohms. Then a dipole with a single fold has a terminal impedance of 300 ohms (four times 75) and a dipole with a double fold 675 ohms (nine times 75). Dipoles with a single fold are extensively used with domestic v.h.f. and u.h.f. aerials as a device for increasing the centre impedance of a dipole which is part of a multi-element array, to counter the reduction in centre impedance which results from the addition of parasitic elements, as we shall see. When the diameter of the limbs of a folded dipole are dissimilar, the impedance modification is not exactly as given above.

Now, when an unbalanced coaxial feeder is connected to a dipole (which, as we have learnt, is itself balanced) the aerial signal has a tendency to travel down the surface of the outer conductor before eventually returning to "earth" at the receiver. The type of unbalanced aerial input circuit at a receiver designed for coaxial feeder is shown in Fig. 2.17 (*a*).

Moreover, the outer conductor of the coaxial cable could also be sensitive to signal pickup. This means that it could pick up signal direct and also interfering signals. The aerial signal flowing in the feeder is shown in Fig. 2.17(*a*) by full lines while the feeder pickup signal is shown in broken lines. It is thus revealed that both aerial and feeder pickup signals are present across the secondary of the coupling transformer in the set.

In the u.h.f. bands, where the signals are often horizontally polarized, just a short length of coaxial feeder diposed horizontally near the aerial may be sufficient to pick up signals, and these signals may tend to cancel out some of the signal picked up by the aerial proper. The effect could also distort the directional characteristics of the aerial, since the outer conductor of the feeder could "look" to the aerial something like an extra badly placed parasitic element, and thus detract from the designed polar response of the aerial (we shall deal with directivity and polar response later). All these factors can result from the use of unbalanced coaxial feeder with a balanced

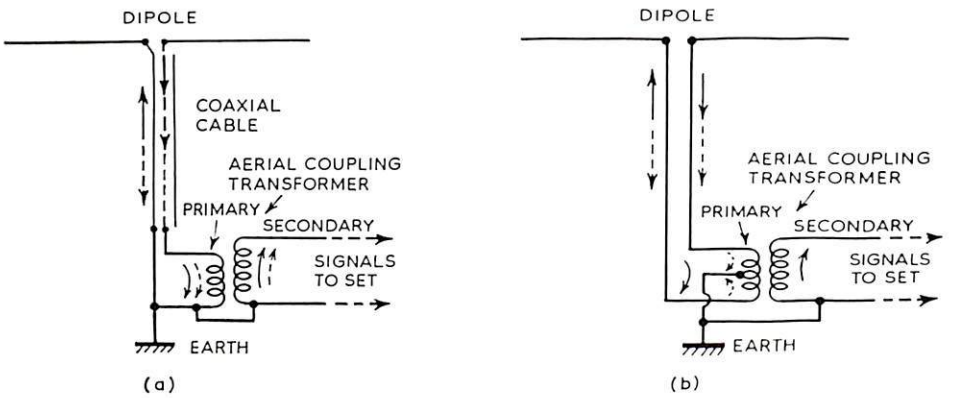


FIG. 2.17. (a) *Unbalanced and* (b) *balanced aerial couplings. The aerial signals are shown in full line and the signals picked up on the feeder in broken line. At* (a) *the interfering signals on the outer conductor of the feeder appear together across the secondary of the aerial coupling transformer, while at* (b) *the feeder signals are cancelled out due to the centre-tap action of the primary of the coupling transformer.*

dipole, particularly on the u.h.f. channels where a half-wavelength may only be 7 or 8 inches!

The effects are by no means as troublesome on the v.h.f. channels, particularly the Band I channels where the signal is vertically polarized. Aerials designed for the reception of u.h.f. television signals, therefore, often incorporate a balun to "match" the balanced dipole to unbalanced coaxial cable, but there are some such aerials whose design appears not to need balun coupling to coaxial cable.

Fig. 2.17 (*b*) shows a dipole connected to a "balanced" input circuit of a receiver. Again, the aerial signals are represented by the full lines and the feeder pickup signals by the broken lines. Here, however, since the primary winding of the aerial coupling transformer is centre tapped, the signals picked up by the feeder are cancelled out and only the aerial signal appears across the secondary winding.

The balun allows the dipole to behave truly as a balanced device while giving the advantages of coaxial cable feeding, which are lack of proximity effects, ease of installation, ease of design of the receiver aerial coupling circuits and so forth. It is extremely difficult to secure optimum balance at the set end by the use of a tapped primary winding, as in Fig. 2.17 (*b*), anyway.

TYPES OF BALUN

There are various types of balun, and a simple arrangement is shown in Fig. 2.18. This works as follows. Suppose that a transmitter is feeding signal

energy up the 75 ohm unbalanced feeder, between the inner conductor and the inside of the outer conductor in the ordinary way, to conductors A-B of the balanced output (these, of course, would normally be connected to the dipole). Because of the unbalanced effect due to the "earthing" of the outer conductor of the feeder, a signal will return towards the transmitter down the outer conductor of the coaxial feeder. That is, some of the signal at point A will travel into the aerial and some of it will travel down the feeder to point C.

The outer conductor at point C on the feeder is connected back to point B, via a quarter-wavelength conductor, which in this case is simply a suitable length of "dummy" coaxial with the inner and outer conductors shorted at each end. It is simply a conductor, therefore.

The signals at points A and B are of opposite phase to each other, of course. This means that the signal from B arrives at point C on the outer conductor of the feeder after going through exactly the same phase shift as the signal also arriving at C from A. This is because point A is connected to point C through a quarter-wavelength of feeder while point B is connected to point C also through the quarter-wavelength of dummy coaxial.

The signals from A and B at point C, therefore, are still in phase opposition, as they are actually at points A and B. The net result is that the signals cancel out at point C on the feeder outer conductor. The arrangement has, in effect, made point C on the feeder "earthy", instead of point A (which would be "earthy" without the quarter-wave section), and produced a balanced condition at points A and B.

It should be noted that a complete half-wavelength exists between A and B, through C, which means that the device does not influence the impedance at the dipole, for here the impedance of a resonant half-wave section is high, just as it is at the end of a half-wave dipole!

It is sometimes necessary to achieve a balanced connection at the dipole at, say, 300 ohms and an unbalanced termination of 75 ohm coaxial feeder. For this a balun with a 4-to-1 impedance ratio is demanded, and an arrangement using a half-wave loop of feeder is shown in Fig. 2.19 (*a*). An equivalent

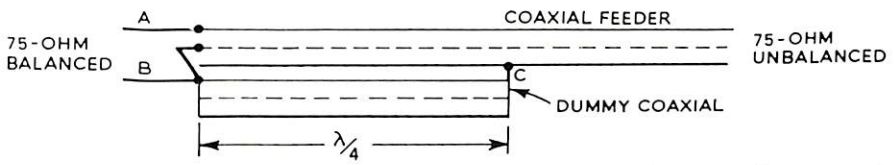


FIG. 2.18. *By the use of a quarter-wave connection from the terminal connected to the inner conductor of the feeder to point C on the feeder, a balun action is created which effectively makes point C "earthy" and points A and B balanced (see text). Note the use of lambda (λ) for wavelength.*

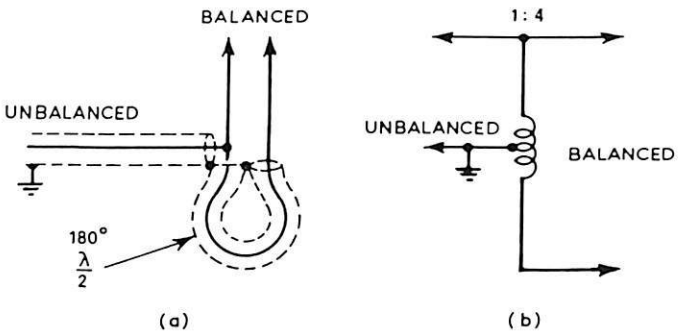


FIG. 2.19. (a) *A half-wave section giving a 4-to-1 balun action.* (b) *The equivalent circuit.* (*Antiference Ltd.*)

transformer producing similar conditions is shown in Fig. 2.19 (*b*). The half-wave section works in a manner similar to that already described (also see below), but the 180 deg. phase effect provides the impedance transformation.

Another interesting form of aerial balun is called the J-Beam "Inverse Balun". The subject of a patent, this is housed in a moulded junction unit with a self-sealing cable aperture for fully waterproof cable connections. How it works can be understood by referring to Fig. 2.20.

At (*a*) is an ordinary folded dipole with 300 ohms terminal impedance, as already considered. If a quarter-wave shorted "stub" (A) is connected across its terminals, as shown at (*b*), the effective bandwidth of the dipole is increased. We shall see later that u.h.f. aerials in particular require a relatively wide bandwidth to embrace all channels of a local group of stations.

At (*c*) the quarter-wave shorted stub is replaced by a half-wave length

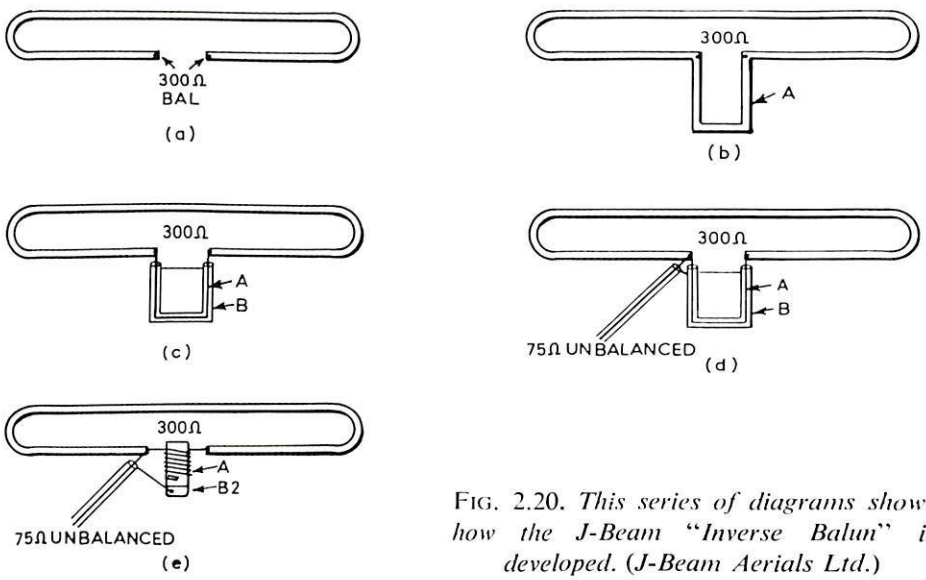


FIG. 2.20. *This series of diagrams shows how the J-Beam "Inverse Balun" is developed.* (*J-Beam Aerials Ltd.*)

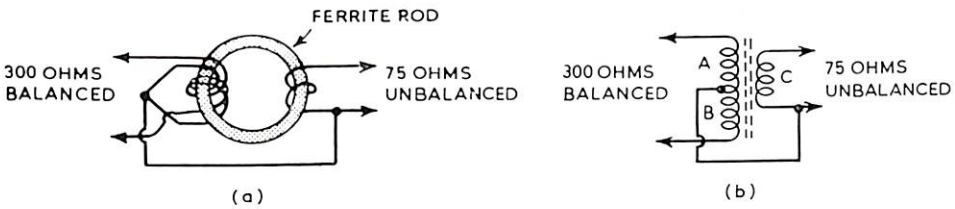


FIG. 2.21. *How to make a* 4-*to*-1 *balun on a ferrite bead.* (a) *shows the construction and* (b) *the equivalent circuit. This kind of transformer has a very wide bandwidth.*

FIG. 2.22. 1-*to*-1 *ratio ferrite balun using the "transmission line" principle.* (a) *shows the physical makeup and* (b) *the theoretical concept. This type of transformer has very low loss and wide bandwidth.*

of coaxial cable, retaining the conditions, the stub here being marked A and the outer conductor B. At (*d*) the impedance between the dipole terminals is still 300 ohms unbalanced; but by connecting one of the dipole terminals to the inner conductor of the coaxial feeder and the outer conductor of the feeder to the outer conductor of the half-wave stub B, the impedance at this point then becomes 75 ohms unbalanced. In effect, the other dipole terminal is fed via an electrical half-wavelength of cable, giving 180 deg. phase shift, the conditions thus being the same as those shown in Fig. 2.19 (*a*).

In (*e*) the outer conductor B of the half-wave section is "lumped" into a former B2. The inner conductor A is non-inductively wound (i.e., bifilar wound) on the former, insulated wire being used. The arrangement then performs in a similar manner to that at (*d*). The insulator between winding A and the former B2 determines the characteristic impedance and the velocity factor of the half-wave section.

FERRITE-CORED BALUNS

Baluns are very simple to make, and of recent years the author has been experimenting with ferrite beads acting as cores for such transformers. An example of a 4-to-1 balun using this technique is shown in Fig. 2.21. Construction details are given at (*a*) and the equivalent circuit at (*b*). Windings A and B are wound in parallel together on the core, just a couple of turns of wire, while winding C (also two turns) is wound separately, and the windings are interconnected as shown.

A 1-to-1 ratio ferrite core balun is given in Fig. 2.22. This is after a design put forward by C. L. Ruthroff in the August 1959 edition of *Proc. I.R.E.* The physical makeup of the device is shown at (*a*) and the theoretical concept at (*b*). This transformer is equivalent to a transmission line, and specimens constructed reveal the very wide bandwidth.

DIPOLE BANDWIDTH

Although a half-wave dipole aerial tunes to a specific frequency, it also responds reasonably well to signals falling within a range either side of the resonant frequency. The dipole thus has bandwidth. An f.m. or television dipole behaves like an unselective tuned circuit (highly damped) and has a bandwidth of around 5 MHz on either side of resonance before the response drops to 0·7 (3 dB) of the maximum, as shown in Fig. 2.23.

The bandwidth is governed by the length/diameter ratio of the conductor comprising the dipole, and it increases as this ratio is reduced. If the ratio is too great (for instance, by the use of a very slender conductor for a television aerial), the bandwidth will be insufficient to pass without attenuation the sideband components of the vision signal and the quality of the picture will suffer as a consequence. Most domestic television aerials are thus constructed of $\frac{3}{8}$ in. to $\frac{3}{4}$ in. tubing.

From this it follows that a dipole of a given conductor diameter increases in bandwidth as its length is reduced to tune to higher frequencies (shorter wavelengths). This is, in fact, the case, which is one reason why a Band IV or V dipole has an inherent bandwidth somewhat greater than that of a Band I dipole. Clearly, as the length is reduced the length/diameter ratio reduces and the bandwidth rises.

The bandwidth of a slender dipole tuned, say, to around 40 MHz for Band I, Channel 1 television is barely adequate for high-definition reception. In practice, however, the inherent bandwidth of a $\frac{1}{2}$ in. diameter dipole is about 10 to 12% of its resonant frequency. This is almost doubled by a single fold. Length/diameter dipole ratios are usually of the order of 100 to 200.

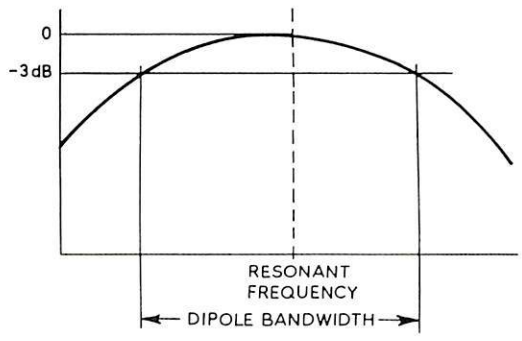
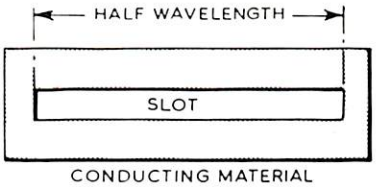
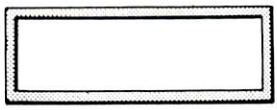


FIG. 2.23. *Illustrating aerial "bandwidth".*

The bandwidth and response characteristics of an aerial can be selected when parasitic elements are fitted by adjusting the length and spacing of these, relative to the dipole. More is said about this in Chapter 3 (see page 70).





(Left) FIG. 2.24. *Basic slot aerial. The length/width ratio governs the bandwidth.* (Right) FIG. 2.25. *When the metal round the slot is reduced as much as physically possible, the result is a "skeleton slot", used on some commercial television aerials.*

SLOT AERIALS

Another type of aerial which is effectively resonant is the "slot". This simply consists of a sheet of conducting material in which a slot is cut, as shown in Fig. 2.24. The length of the slot approximates half a wavelength of the required signal, while the width—as with a conducting dipole—influences the bandwidth. The conducting material round the slot should extend over at least a quarter of a wavelength for the best reception, but in practice it is found that this is not always essential, particularly at the upper v.h.f. frequencies and where the "slot" forms a part of an aerial array. The element is then termed a "skeleton slot", as shown in Fig. 2.25.

Connection to the slot can be made at two opposite points at the centre as shown in Fig. 2.26 (*a*). At these points the impedance is of the order of 600 ohms, balanced, so connection must be made with feeder of corresponding characteristics. A lower impedance feeder can be used in conjunction with a matching device, as explained earlier, or the connections can be displaced from centre, as at (*b*).

Low-impedance coaxial feeder can be connected to a slot as shown at (*c*). Here a "stub" (ordinary conductor) half the length of the slot is suspended centrally between the parallel edges by an insulating cord or spacers. The outer conductor or braid of the feeder is then connected electrically along the edge of the slot, the inner conductor being connected to the "stub".

The slot aerial polarizes the wave in the opposite sense to the conventional dipole. It thus needs to be vertically disposed to radiate or receive a horizontally polarized signal.

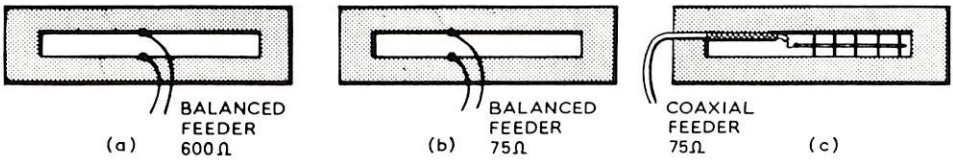


FIG. 2.26. *Methods of "feeding" a slot:* (a) *with* 600 *ohm balanced feeder at centre,* (b) *with* 75 *ohm balanced feeder off-centre,* (c) *with* 75 *ohm coaxial cable via a "stub".*

CHAPTER 3

Practical Aerial Systems

FOR domestic radio reception, the ferrite rod type of aerial has practically superseded the frame aerial (used in vintage portable sets) and long-wire m.f. aerials of years gone by. The ferrite rod aerial is really a condensed frame aerial, the windings being wound on a rod or bar of ferrite material instead of on a large frame with air as the core. Like the frame aerial, therefore, the ferrite rod aerial serves the dual function of picking up radio signals and of tuning the front end of the receiver to which it is connected.

Ferrite rod aerials are used in all transistor portable receivers and are also found in many of the larger type of sets and radiograms, to avoid the need for external aerials. At present, they work mainly on medium frequencies, but there is a possibility that they may later be developed for use on the television bands. Already an experimental ferrite rod aerial has been made for use on Band II, for reception of f.m. radio signals.

Ferrite is a non-conducting material of high permeability. Permeability is the measurement of the ability of a substance to concentrate magnetic lines of force. Thus, the greater the permeability, the more will the substance concentrate the magnetic lines of force. Permeability is measured as the ratio of the number of lines in the material to the number of lines in the same area in air.

FRAME AERIAL

Before going any further, we must consider one or two things about the frame or loop aerial, as it is sometimes called.

The aerial is wound on a frame, usually of equal length sides, and in effect forms a coil of specific inductance. This inductance is resonated to the required signal frequency by a variable capacitor connected in parallel with it, as shown in Fig. 3.1. The amount of signal that such an arrangement picks up is governed by the area of the loop: the greater the area, the greater the signal induction. Actually, the area also affects the "radiation resistance" of the aerial: the larger the area, the greater the radiation resistance.

The frame aerial is directional and has a figure-of-eight polar diagram, the direction of minimum response being along the axis of the loop. This

sort of aerial responds to the magnetic field of the radio wave, and the null response directions occur because of signal cancellation at each side of the loop. Effectively, when the loop is orientated for maximum response the signals picked up add together.

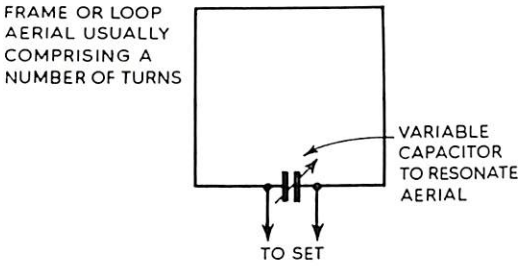


FIG. 3.1. *Simple frame or loop aerial. This is resonated by the tuning capacitor to the required frequency.*

The efficiency of the aerial also depends on the "Q" or "goodness value" of the winding. The "Q" factor can be enhanced by winding with Litz wire of about 9/40 s.w.g. Frame aerial winding data is given in Table 3.1.

FERRITE ROD AERIAL

An extension of the loop aerial is the ferrite rod aerial. Here, however, instead of air as the loop core high-permeability ferrite material is used. The permeability of air is unity, while that of ferrite materials is 200 or higher. It will thus be appreciated why the ferrite rod aerial is much more efficient than the ordinary frame aerial. The magnetic component of the signal is concentrated through the turns of the coils wound upon it, which means that each turn effectively picks up more signal than it would without the core. The ferrite can be considered as enlarging the dimensions of the aerial coils without spreading the signal field induced into the coils. This avoids many of the proximity effects of the conventional frame aerial.

The action of the ferrite rod also endows the tuned aerial circuit with high "Q" factor.

The maximum pickup in a ferrite rod aerial is when the rod is in line with the magnetic component of the radio signal, as shown in Fig. 3.2 (*a*) and minimum when the rod is at right-angles to the magnetic field (*b*). The longer the core, the greater the concentration of the lines of signal field.

Table 3.1

FRAME AERIAL WINDING DATA

Length of Side of Square Frame (ft.)	*No. of Turns*	*Space Between Wires (in.)*	*Inductance (μH)*	*Natural Wavelength (metres)*
8	3	$\frac{1}{2}$	96	160
6	4	$\frac{1}{4}$	124	170
4	6	$\frac{1}{4}$	154	175
3	8	$\frac{1}{8}$	193	185

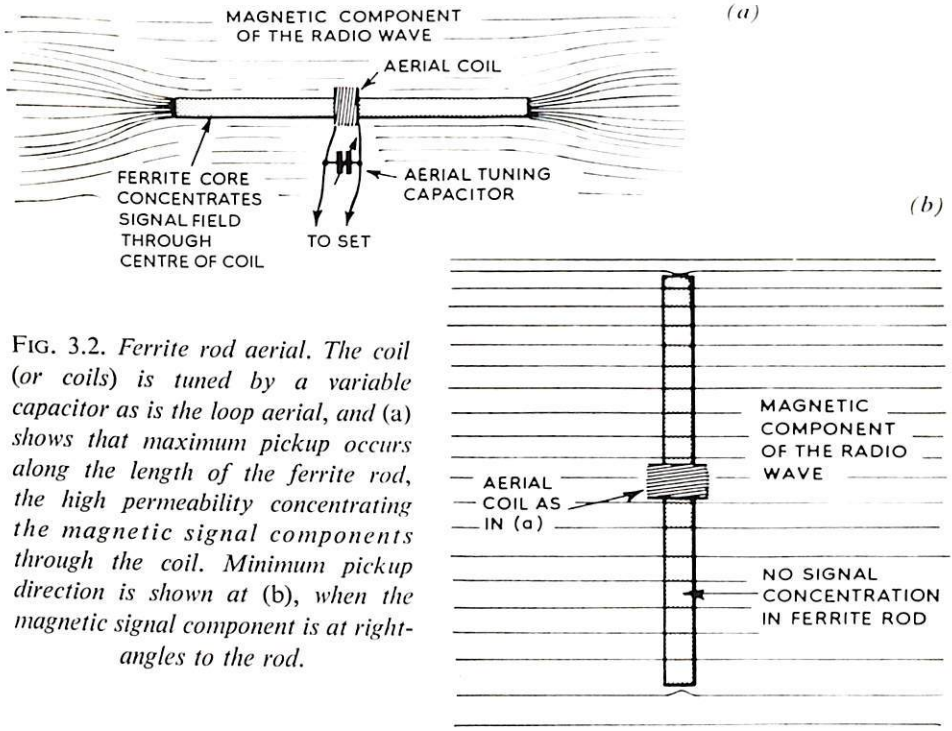


FIG. 3.2. *Ferrite rod aerial. The coil (or coils) is tuned by a variable capacitor as is the loop aerial, and* (a) *shows that maximum pickup occurs along the length of the ferrite rod, the high permeability concentrating the magnetic signal components through the coil. Minimum pickup direction is shown at* (b), *when the magnetic signal component is at right-angles to the rod.*

The ferrite core also increases the inductance of the coils wound upon it over their free-air inductance. This means that fewer turns of wire are required to tune to a given frequency than without such a core. This, again, tends to enhance the effective "Q" of the tuned circuit.

In a receiver, the coils are arranged to tune over the long and medium wave bands by the tuning capacitor. However, the inductance of the coils on the ferrite rod can be varied a little by sliding them along the rod. The inductance is maximum when the coils are placed at the centre of the rod, and it tends to drop as the coils are moved either side of centre. This action is performed when aligning a portable with ferrite rod aerial, so as to secure optimum sensitivity of the aerial circuit.

Two or more coils are often featured on the ferrite rod for medium waves and long waves, with a small coil for coupling in an external aerial, such as a car-type aerial when the set is used inside a car, the signals then being screened from the aerial proper by the metal body. More is said about this problem later. In some models, two ferrite rods are used, one for medium waves and the other for long waves, to secure optimum efficiency on each band.

A typical ferrite rod aerial may consist of a ferrite rod about 8 in. long

by $\frac{5}{16}$ in. diameter, with narrow, layer type coils wound in formers. The LW coil may consist of about 140 turns of 42 s.w.g. insulated copper wire and the MW coil 45 turns of 9/46 Litz wire.

Loop and ferrite rod aerials have applications other than for the reception of broadcast signals. One such application is for direction finding. For ordinary receiving applications, the directivity effect of this kind of aerial can often be used to advantage; for instance, for improving the signal/interference ratio in cases where the interfering signal is close to the frequency of the wanted signal. The idea is to orientate the aerial until the null response point is pointing towards the unwanted transmission; along the axis of the rod in the case of ferrite rod aerials and along the axis of the loop in the case of frame aerials. Maximum pickup occurs when the line of signal path is at right-angles to the ferrite rod.

When a ferrite rod aerial is used in transistor portable sets, the whole set usually has to be orientated for the best signal pickup or, conversely, for minimum response to an interfering signal. However, when used in larger domestic sets, the aerial can usually be rotated inside the set for the best overall reception of the local stations. Some sets feature an arrangement whereby the aerial can be rotated by means of a control knob at the front or side of the cabinet.

BAND II FERRITE ROD AERIAL

The development of v.h.f. and u.h.f. ferrite rod aerials is dependent on the availability of a ferrite material which retains a reasonable permeability and sufficiently low losses up to 200-odd MHz for the v.h.f. channels and up to 800 or 900 MHz for the u.h.f. channels. Most ordinary ferrite materials are suitable for frequencies up to a maximum of 10 MHz, but there have been developments along these lines which have resulted in a ferrite responsive up to about 100 MHz. From this has been made an effective f.m. ferrite rod aerial.

The prototype aerial is tuned over Band II by means of a variable resonator, which makes the permeability of the rod variable, and hence the frequency to which it tunes. The prototype (described fully in *Philips Technical Review*, Vol. 24) uses a ferrite rod of 16 cm long and 2 cm diameter, incorporating a special resonator device 14 cm long. The relative permeability of the ferrite is about 25, and the coupling is such that a bandwidth in the order of 1 MHz is achieved.

One problem in using ferrite rod for outdoor or indoor television aerials is the wideband matching between the aerial and the cable (apart from the ferrite problems as already mentioned). There will certainly come a time, however, when ferrite materials will be used more extensively, but it seems to be somewhat distant at the time of writing.

For distant m.f. reception the long-wire aerial or the anti-interference type of aerial, described in Chapter 2, is still employed. Some anti-interference aerials employ twin feeder with an outer braid acting simply as a screen, instead of coaxial cable. The "balanced" feature of twin feeder helps with the cancellation of interference picked up on the feeder. Balanced transformers are then used for matching at the ends.

SHORT-WAVE DIPOLE

We have already seen that the dipole as a tuned aerial would be too long for the m.f. bands. Such an aerial, though, is employed for short-wave reception (and transmission). A short-wave dipole aerial is depicted in Fig. 3.3. Connection at the centre low-impedance point is made to the downlead or feeder. Twin feeder is generally used on this type of dipole, but coaxial feeder could be used with or without a balun. As the losses at h.f. are somewhat below those at v.h.f. and u.h.f., the short-wave dipole can be connected to the set through twisted flex, but special feeder is to be preferred to keep the feeder losses at the absolute minimum.

The aerial input circuit of the receiver using this kind of aerial must be of balanced or unbalanced characteristics and low impedance to match the feeder. Most ordinary broadcast sets (and some communications sets) have just a single aerial terminal with a high-impedance characteristic to accept all signals. Connection to this and the earth terminal of a low-impedance feeder would heavily damp the circuit and greatly impair the signal transfer efficiency. Thus, sets with this type of input must either be connected to a high-impedance aerial or to a low-impedance feeder (as derived from the centre of a tuned dipole) through a matching transformer having minimum losses at the required operating frequency.

Users of short-wave or all-wave sets desirous of achieving optimum

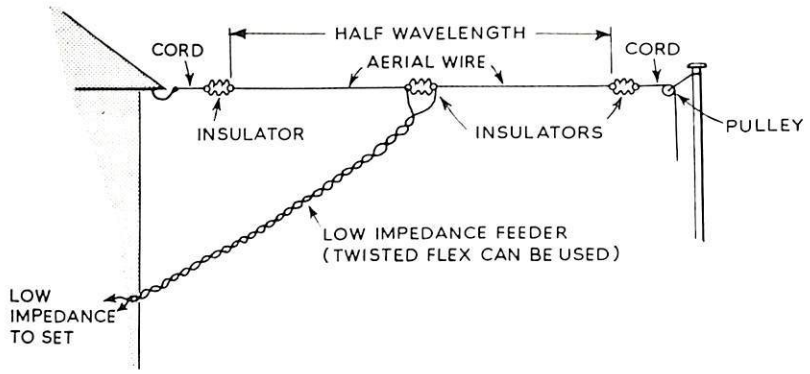


FIG. 3.3. *Details of a simple short-wave dipole aerial.*

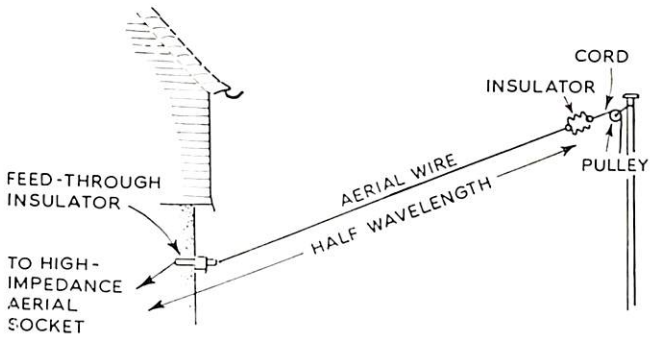


FIG. 3.4. *High-impedance feeding is possible, as this illustration shows.*

short-wave response in the absence of a low-impedance dipole matching circuit could arrange for the end of the tuned dipole (at which point the impedance is high, as we have already seen) to connect to the aerial socket of the set. Although the performance is not likely to be so good as when a properly matched centre-fed dipole is used, via an impedance matching device, it should be better than the use of a random length of wire (see Fig. 3.4). Chapter 2 describes how the length of a dipole to tune to any frequency can be discovered (see page 46).

Dipole Too Short or Too Long. If a dipole is shorter than half the wavelength of the received signal, it "looks" to the set as a resistance in series with a capacitance; if it is longer it "looks" like a resistance in series with an inductance; and, as we have seen, when it is exactly the right length it "looks" like a true resistance. The reactive element can be neutralized in practice by connecting an inductance in series with a too-short dipole or a capacitance in series with a too-long dipole. This method, particularly the former, is often used to "tune" compressed dipoles fitted inside v.h.f. f.m. sets. More is said about this later.

Harmonic Dipole. At this point, it is interesting to see how a centre-fed half-wave dipole can also be used to tune odd harmonic frequencies without altering its original length. Fig. 3.5 shows the current distribution along a dipole due to a signal three times the frequency to which the dipole is cut. It will be seen from this that the centre of the dipole is at the same low impedance as when it is responding to a frequency equal to its half wavelength. This means that a dipole cut to a specific frequency will also respond, and provide correct matching, to a signal three times the specific frequency.

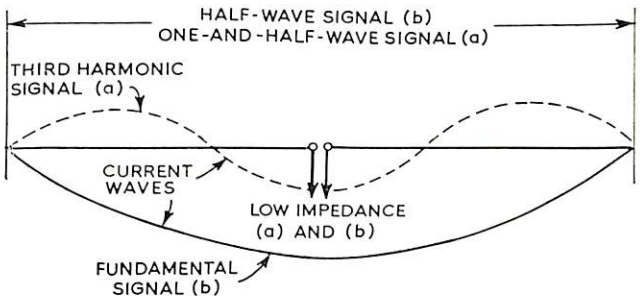


FIG. 3.5. *Illustrating the way a harmonic aerial works.*

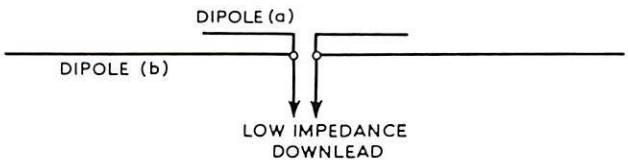


FIG. 3.6. *Two dipoles can sometimes be coupled as shown when the dipole not in use represents a high impedance to the feeder and the dipole in use represents a low impedance in the usual way.*

Indeed, the pattern holds good for all odd harmonics. As an illustration, a dipole cut to tune, say, to 7 MHz will also respond to the 21 MHz band (these being two amateur bands, as some readers will appreciate).

The length of a three half-wave (or 1½-wavelength) aerial can be found from the expression:

$$\text{Length in feet} = 492 \times 2{\cdot}95/\text{frequency in MHz.}$$

Dipole Coupling. It is also sometimes possible to couple two dipoles to a common downlead, as shown in Fig. 3.6. This is possible when the lengths of the two aerials are such that the one not in use acts as a high impedance to the feeder, while the one in use acts as a low impedance to the feeder. The former thus does not greatly influence the latter. This technique is sometimes adopted with television and f.m. aerials, one aerial being tuned, say, to a Band I channel and the other tuned to Band II, the f.m. band.

For the sake of those readers interested in amateur radio reception and transmission, Table 3.2 gives the length of the dipole required to tune to the centre of the amateur bands.

A dipole can be either erected vertically, as a rod, or horizontally, depending upon the polarization of the signals to which it is to respond. Most short-wave signals are horizontally polarized (though the polarization does tend to vary due to propagation influences—see Chapter 1), meaning that the aerial is best arranged to be horizontal to the earth (see Fig. 3.3). The f.m. signals in Band II, and also some television signals in Bands I, III, IV and V

Table 3.2

DIPOLES FOR THE AMATEUR BANDS

Amateur Band (metres)	*Dipole Length (ft.)*
80	128
40	66·3
20	33
15	22
10	16·25

are horizontally polarized. Thus, an aerial suitable for the reception of these has itself to be horizontally disposed for the best results. The question of polarization is dealt with in Chapter 1.

DIPOLE DIRECTIVITY

Now, a dipole vertically disposed is theoretically non-directional in the horizontal plane. The term generally used is "omnidirectional", meaning that the aerial has no favoured direction of acceptance to signals of its polarization and responds equally to vertically polarized signals arriving at right-angles to it from all directions. However, when this same dipole is mounted horizontally it becomes "bi-directional". This means that it responds most to horizontally polarized signals arriving at right-angles to its length and least to horizontally polarized signals arriving along its axis.

These conditions exist because for normal transmission and reception it is the directivity in any one plane which is important, and the two planes ordinarily adopted are vertical and horizontal. Clearly, a dipole has a three-dimensional response characteristic, but because of the polarization of the signal itself its response can be looked upon in two planes only.

The response or directivity of an aerial relative to the conditions mentioned is revealed by what is called a "polar diagram". Polar diagrams of a dipole vertically and horizontally disposed are shown in Fig. 3.7 at (*a*) and (*b*) respectively. The dot in the centre of the circle at (*a*) represents the top of the dipole and the distance from the dot to the "contour", which is the circle, is a measure of the field strength round the dipole or the pickup sensitivity of the aerial. The short line at (*b*) represents the horizontally disposed aerial, and in accordance with the explanation for (*a*), the contours show that the aerial responds to signals arriving broadside while rejecting signals arriving along its axis.

In Chapter 1 it is shown how unwanted signals arriving at the aerial can give rise to bad interference, including "ghost" effects on vision. In practice,

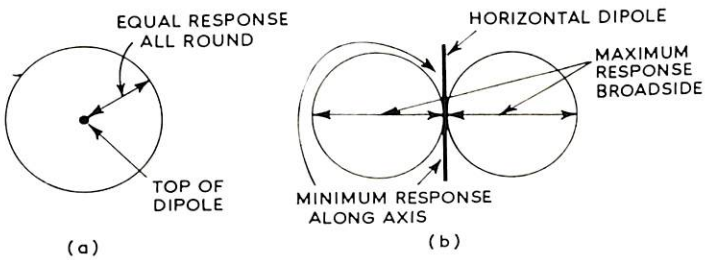


FIG. 3.7. *Polar diagrams of* (a) *vertically mounted dipole and* (b) *horizontally mounted dipole, the former responding to vertically polarized signals and the latter to horizontally polarized signals.*

these problems are minimized by the use of a directional aerial orientated in such a way that the wanted signal gives maximum response and the unwanted signal minimum response, thereby maintaining the highest possible signal/interference ratio.

For example, if an interfering signal is arriving at a horizontal dipole 90 deg. off the direction of the wanted signal, maximum interference discrimination would be achieved simply by turning the aerial until it is pointing along the direction of the interfering signal. Under this condition, the wanted signal would be arriving at right-angles to the aerial. Thus, there would be maximum response to the wanted signal and minimum response to the unwanted signal, giving optimum signal/interference ratio. This ideal condition is shown in Fig. 3.8 (*a*).

Unfortunately, this ideal rarely occurs, for the interfering signal may be only a few tens of degrees off the direction of the wanted signal or 180 deg. off direction. In either case, a simple horizontal dipole would offer very little discrimination against the interference, as shown at (*b*) and (*c*) in Fig. 3.8. A vertical dipole, of course, would offer no discrimination at all under any condition.

PARASITIC ELEMENTS

From the point of view of f.m. radio and television reception, aerials of greater directivity than given by the dipole alone are employed in all but high signal-strength, low interference-reception areas. A dipole aerial can be made directional simply by placing "parasitic" elements either side in parallel with it. The term "parasitic" implies that these elements or conductors have no direct electrical connection to the dipole proper.

There are two kinds of parasitic element mostly used in the aerials being considered in this book, called the "reflector" and "director". The former

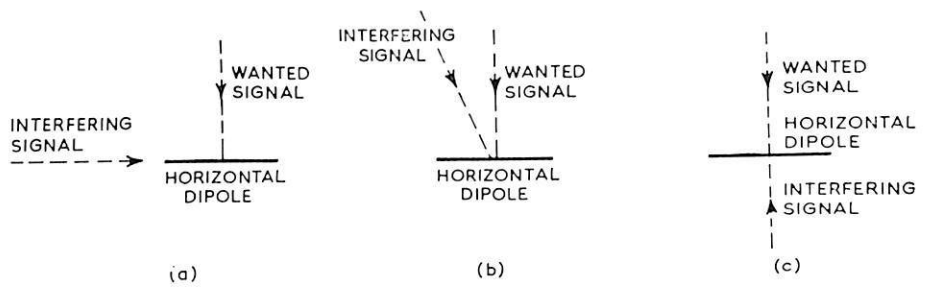


FIG. 3.8. *Interference discrimination by a horizontal dipole.* (a) *shows the condition of maximum signal/interference ratio where the interfering signal is arriving* 90 *deg. off the wanted signal. The simple horizontal dipole would give virtually no discrimination against interfering signals arriving relative to the wanted signal as in* (b) *and* (c). *This diagram should be studied along with that in* FIG. 3.7 (b).

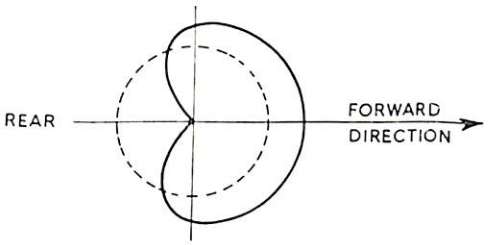


FIG. 3.9. *Polar diagram of a dipole and reflector aerial ("H" type aerial) with the reflector a little longer than the dipole and spaced by 0·25 wavelength. The dotted-line circle gives the approximate response of a single, vertical dipole. Note the suppression at the rear and the slight increase in forward response.*

is placed behind and the latter in front of the dipole relative to the direction of arrival of the signal. These are conductors of almost the same length as the dipole and are usually made of the same material and have the same diameter (except in the case of some u.h.f. television arrays). Their distance from the dipole is important and this depends on the operating frequency, bandwidth, impedance and directivity of the array.

Parasitic elements are best considered in terms of a transmitting aerial. In this light, let us consider first the reflector.

Reflector. When a reflector is placed near a dipole coupling occurs between it and the dipole, rather like the coupling between two tuned circuits. Thus, if a dipole is connected to a signal source it radiates in the ordinary way and some of the radiation is coupled to the director. This, then, is endowed with a voltage/current distribution like that along the dipole itself (see Fig. 2.6). There may be a little difference because the reflector is a continuous length of conductor while the dipole is broken in the centre to accommodate the low-impedance feeder.

The reflector then radiates its own signal. However, because of the signal coupling from the dipole to the reflector, the signal induced into the reflector is out of phase with that in the dipole. A further phase shift occurs when the *radiated reflector signal* arrives back at the dipole. This re-radiated signal, in fact, tends to cancel the dipole signal. Now, if the total phase rotation amounts to 180 deg. complete cancellation of the signal occurs at the reflector side of the dipole and the dipole radiates then only in the opposite direction, as shown by the polar diagram in Fig. 3.9.

In other words, the aerial has been made more directional than hitherto, having very little pickup at the rear (remember that the effect will be the same for receiving as for transmitting). The aerial is then able to handle interference difficulties far better than the ordinary dipole.

The overall phase rotation of the signal (i.e., from the dipole to the reflector and from the reflector back to the dipole) is governed by the length of the reflector and by its spacing distance from the dipole. If the reflector is made a few per cent longer than the dipole (bearing in mind that it has no insulator at the centre, etc.) and is spaced by a quarter of the wavelength

to which the dipole is cut, then the signal undergoes a 90-deg. phase rotation due to the coupling from the dipole to the reflector, and a further 90-deg. phase rotation due to the reflector radiating signal back again to the dipole. Under this condition, a polar diagram approximating that in Fig. 3.9 is produced.

If the reflector/dipole spacing is less than a quarter-wavelength, the rear of the aerial still picks up some signal, although the forward pickup is greater. Fig. 3.10 (*a*) shows the polar diagram created by about a tenth of a wavelength spacing. As the spacing is increased beyond a quarter-wavelength, a rear lobe occurs on the polar diagram, and Fig. 3.10 (*b*) shows the effect with a spacing of about half a wavelength.

Similar variations in polar diagram occur when the reflector/dipole spacing is fixed and the *length* of the reflector is changed. This is because the phase of the signal radiated from the reflector is closely related to its length or its tuning relative to the received signal frequency. This is much the same as tuning one circuit of a pair of tuned and coupled circuits. Some practical aerials are made with a reflector/dipole spacing of 0·15 wavelength and the polar diagram (Fig. 3.9) is obtained by carefully arranging for a critical reflector length.

Clearly, the tuning of the reflector will vary as the signal frequency is varied. This means that while an aerial may have a desirable polar diagram at one frequency, this may be entirely different at another frequency, somewhat off tune from the aerial frequency. Here, in fact, is one of the problems associated with the design of wideband television aerials.

The creation of aerial directivity generally increases the gain in the direction of forward response over that of a dipole without the presence of parasitic elements. Of course, if the design of the aerial produces a lot of small side lobes in addition to the main lobe, the gain in the direction of the main lobe would be below what it would be if all the power in the small lobes was concentrated into the main lobe. Some idea of the effect of the extra gain of directivity can be gleaned by considering an ordinary spherical toy balloon. If this is compressed in the hand, say, at the edge, it will expand forward, while if it is compressed so that it divides into two halves, then the expansion either side will be less.

The idea, then, with an aerial is to concentrate maximum power in the required direction of the signal, leaving little power behind to form unwanted side and rear lobes. Of course, some aerials may be designed specially to have more than one forward direction of response. The response (or pickup sensivitity) of the polar diagrams given in Figs. 3.9 and 3.10 are shown relative to a dipole, the dipole polar diagram in vertical polarization being given by the dotted line.

Impedance Effect. There is also another very important aspect with

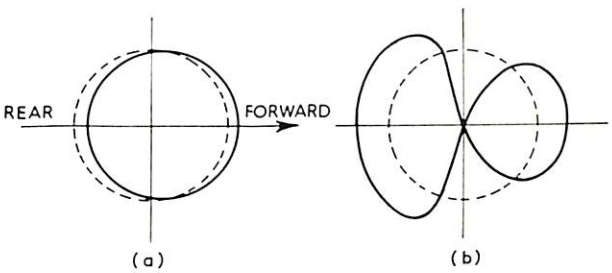


FIG. 3.10. *Showing the effect that parasitic element spacing has on the polar diagram: (a) with 0·1 wavelength spacing and* (b) *with 0·5 wavelength spacing.*

regard to the addition of parasitic elements to a dipole aerial, and that is the effect on dipole impedance. Generally speaking, the dipole impedance decreases with the addition of parasitic elements, but just how it diminishes depends on the number and nature of the parasitic elements and on the signal frequency relative to the tuned frequency of the aerial. Normally, an aerial of correct frequency will be used for the transmission, but it is worth remembering that if an incorrect frequency or channel number aerial is used, not only will the gain, directivity and polar response be affected, but also the matching to the feeder.

When a single reflector element is used, the effect on the centre impedance of the dipole is not excessive and special matching arrangements are not usually needed. However, when several parasitic elements are used, the centre impedance of the dipole often falls to a very low value, demanding the use of either a folded dipole or an impedance transformer to restore the dipole impedance to a value to match that of the feeder.

Only a single reflector *system* is generally employed. This often takes the form of a single rod, though it may consist of several rods or metal mesh of specific area in the case of u.h.f. aerials. Nevertheless, the reflector *system* is counted as one "element".

Directors. Thus, to further improve directivity subsequent parasitic elements take the form of directors. It is possible to employ more than one director element; or an aerial may consist of a dipole and one director, instead of a reflector. Multi-element arrays, however, consist of the dipole, one reflector system and a number of directors. Less complex aerials consist of the dipole plus one reflector and one director (three-element array). High-gain u.h.f. aerials often feature ten or more directors.

Directors are usually a few per cent shorter than the dipole, and they may diminish in length progressively from the dipole, but this is not a general law.

The operation of the director or directors can be considered by looking upon the aerial as a radiator. The dipole radiates and also induces a signal current into the first director. This then itself radiates and induces current into the second director, the process continuing to the final director. Each

director is effectively "loaded" by elements to the front and back of it, with the exception of the final director which is loaded only on one side. It is for this reason, and to provide maximum radiation in the forward direction, that the final director of an array is sometimes the shortest.

The length of the directors and their spacing from the dipole and from each other are chosen to secure the required pattern of phase advance of signal relative to the dipole, so that the radiation from the directors adds up to provide a net increase in forward radiation. It will be understood that a phase advance occurs because, in fact, the directors are shorter and thus tuned to a higher frequency than the dipole. A similar phase advance occurs in tuned and coupled circuits when the secondary (which is the director in the case of an aerial) is tuned to a higher frequency than the primary (i.e., the dipole in the case of an aerial).

The spacing of the directors is smaller than the reflector/dipole spacing, and while the reflector serves mainly to reduce the response of an aerial in the backward direction, the director gives a boost in the forward direction.

YAGI ARRAY

A dipole aerial working in conjunction with a system of directors and reflector is called a Yagi aerial or array (sometimes called an "end-fire parasitic aerial"), after the Japanese engineer who wrote in English about the work originally published in Japanese between 1926 and 1928 by a colleague, Professor Uda. The Yagi and modified Yagi array are the most popular of all aerials used for the reception of f.m. radio and television signals. Indeed, they form the basis of almost all domestic v.h.f. and u.h.f. aerials, and are also popular with amateurs.

In practice, however, the more directors that are added, the progressively smaller becomes their effect on gain and directivity. After about nine or so directors, not much benefit is derived by adding more. A better idea to secure enhanced gain and directivity is then to couple two, four or more complete arrays together. This technique produces so-called stacked or broadside arrays, the individual arrays being placed one above the other or side by side respectively. More is said about these arrays later.

For the sake of readers who wish to experiment with and build their own Yagi aerial systems, the following expressions will be of value.

Length of dipole (ft) = 468/f(MHz) or (in.) = 5,616/f(MHz).
Length of reflector (ft) = 498/f(MHz) or (in.) = 5,976/f(MHz).
Length of first director (ft) = 450/f(MHz) or (in.) = 5,400/f(MHz).
Length of subsequent directors reduces progressively by 2·5 per cent.
Spacing (0·25λ) reflector/dipole = 246/f(MHz) or (in.) = 3,052/f(MHz).
Spacing (0·13λ) director/dipole = 128/f(MHz) or (in.) = 1,546/f(MHz).
Spacing (0·13λ) director/director = 128/f(MHz) or (in.) = 1,546/f(MHz).

The length of the dipole, in the case of a folded dipole, is measured from the centre of the fold at one end to the centre of the fold at the other end, and the lengths are based on elements of $\frac{3}{8}$ in. to $\frac{1}{2}$ in. diameter.

It must be remembered that the performance of Yagi arrays can only be assessed from all the characteristics already discussed, such as impedance, gain, directivity and bandwidth, and that as there are so many variables, one affecting the other, the dimensions of commercial aerials may differ from those as computed from the above expressions.

It will now be appreciated that a great deal of design thought goes into the production of even the simplest of aerials, and while some of the factors can be derived from calculation others demand the use of elaborate instruments for plotting polar diagrams and directivity and for measuring impedance, bandwidth and so forth. There are so many combinations of element length and spacing, and ways that these can influence the dipole tuning, that it is impossible to explore all the possibilities in a book of this nature. The different aerial manufacturers have their own pet ideas and arrangements, which is why there may appear to be a wide difference between aerials of the same type but of different make, and why the dimensions of a home-made design may differ from those of a commercial design.

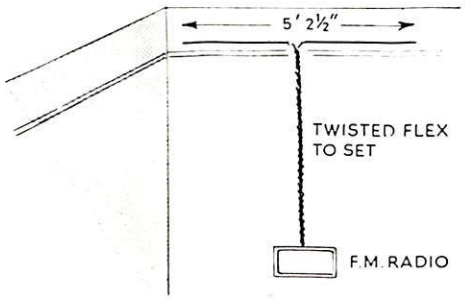
We shall now consider separately the various types of aerials, with the exception of the m.f. aerials which have already been dealt with in some detail.

AERIALS FOR BAND II F.M. RADIO

The f.m. band (Band II) extends from about 87 MHz to 100 MHz, and each local BBC station radiates at least three programmes on three separate carriers. The spacing between these carriers is generally 2·2 MHz, so for an aerial to respond equally to the three signals it must have a bandwidth approaching 5 MHz. The programmes usually carried are Radios 2, 3 and 4. The Radio 2 programme is on the lowest frequency, the Radio 4 programme on the highest frequency, and the Radio 3 programme is placed in the centre. This frequency distribution can easily be remembered by taking the "2" in Radio 2 for "low" and the "4" in Radio 4 for "high", with Radio 3 in between.

In some areas two Radio 4 programmes may be radiated, giving four channels in all. The Oxford Relay Station, for example, radiates the Midland Radio 4 programme on 93·9 MHz and the West Radio 4 programme on 95·85 MHz, in addition to the Radio 2 programme on 89·5 MHz and Radio 3 on 91·7 MHz. In this case it will be seen that the 2·2 MHz spacing does not apply between the two Radio 4 programmes. It does with some four-programme stations, however.

Horizontal polarization is used throughout the f.m. band, and as many



(Left) FIG. 3.11. *A simple f.m. dipole can be made by fixing a suitable length of wire round the picture rail, cutting in the centre and connecting to twisted flex for the feeder to the set.* (Right) FIG. 3.12. *A commercial f.m. dipole (Antiference Ltd.).*

areas now receive quite strong signals from local stations elaborate aerials are not very often required. The simple dipole mounted indoors or outside often provides sufficient pickup to work a modern set or tuner of high sensitivity. A simple indoor dipole need be nothing more elaborate than a suitable length of wire run round the picture rail, cut in the centre and connected to a length of twisted flex for the feeder, as shown in Fig. 3.11. The overall length of the dipole can be 5 ft $2\frac{1}{2}$ in., but if optimum response to the local transmissions is required, then the dipole length should be calculated as shown earlier, using the frequency of the Third programme as the basis for calculation.

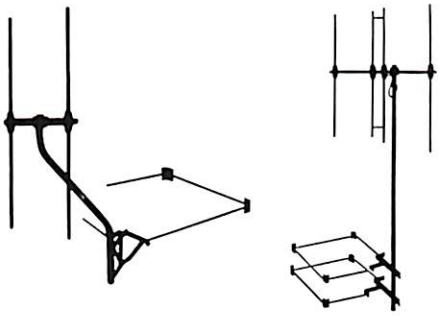
F.m. sets and tuners require a certain strength of aerial signal to cause them to "limit" and to reduce in sensitivity towards amplitude modulation, which is essentially the modulation associated with interference. In some areas sufficient signal cannot be picked up by a simple indoor aerial, so an attic or roof aerial is then needed. In many cases this can consist of a simple dipole, but in fringe areas or in deep towns where the interference level is high, a higher-gain, more highly directional aerial is desirable. Only rarely these days is it necessary to employ an f.m. aerial with more than three elements—dipole, reflector and director.

Fig. 3.12 shows the outline of an f.m. dipole in common use.

AERIALS FOR TELEVISION IN BAND I

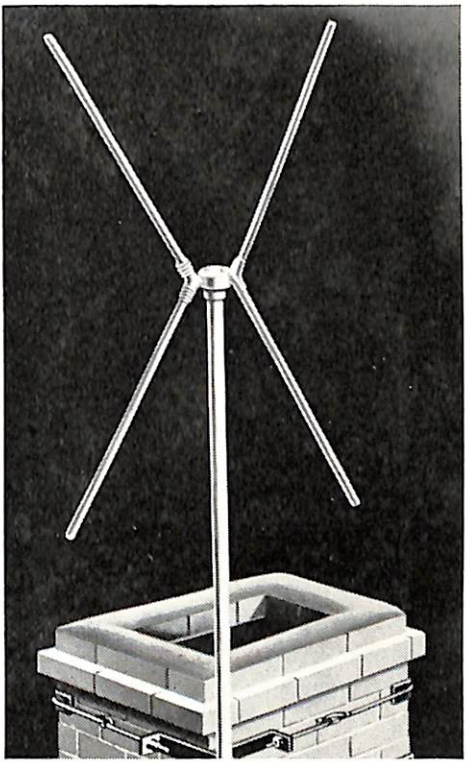
Band I is used exclusively for television, and is divided into five channels, as shown in Table 3.3. At the time of writing, Band I in Great Britain carries only 405-line transmissions, each sound and vision transmission occupying a width of 5 MHz. However, if and when Band I is re-engineered for 625-line transmissions, the channel width will be 8 MHz and the band will accommodate only three such channels.

A 405-line Band I TV aerial, therefore, must have a bandwidth of at least 5 MHz to avoid attenuation of the sidebands of the vision and sound



(Left) FIG. 3.13. *"H" Band I television aerial. (Antiference Ltd.)*

(Centre) FIG. 3.14. *Three-element Band I television aerial adopting the "Tru-Match" principle, which is explained in the text. (Antiference Ltd.)*



(Right) FIG. 3.15. *Band I television "X" aerial. This configuration can consist of either a dipole and reflector or a dipole and director. Folded elements are sometimes used for impedance, and two arrays may be arranged in broadside for extra gain and great directivity.*

signals. Aerials for this service are essentially of Yagi type, though there are now many areas where just a single dipole or "H" type aerial (i.e. dipole plus reflector or director) is adequate. Such an aerial is shown in Fig. 3.13.

In areas where the signal strength is low or interference is high (or both), a three-element aerial, such as that shown in Fig. 3.14, may be desirable.

Incidentally, the aerial shown in Fig. 3.14 is interesting in that it employs a patented method of impedance matching to the feeder. The arrangement, called "Tru-Match" (Antiference Ltd.), differs somewhat from the folded

Table 3.3

405-LINE TELEVISION CHANNELS IN BAND I

Channel No.	*Sound (MHz)*	*Vision (MHz)*
1	41·50	45·00
2	48·25	51·75
3	53·25	56·75
4	58·25	61·75
5	63·25	66·75

dipole matching technique. It will be seen that two dipoles closely spaced are used instead of the conventional dipole. One of these is connected to the feeder while the other is an undriven or parasitic dipole. We have seen that the centre impedance of a dipole falls due to the addition of a reflector and directors, and that the impedance can be increased to match the feeder by folding the dipole.

With the "Tru-Match" principle, the driven dipole is a little *longer* than required for accurate resonance. This increases the impedance of the dipole from the feeder point of view but at the same time introduces an inductive component (as we saw earlier). The non-driven dipole is a little *shorter* than required for accurate resonance and this introduces a capacitive component which cancels out the inductive component. The nature of the dipole terminal impedance is then truly resistive, the actual value of the impedance being determined by the ratio of the drive/non-driven dipoles and the spacing between them, called the "coupling factor".

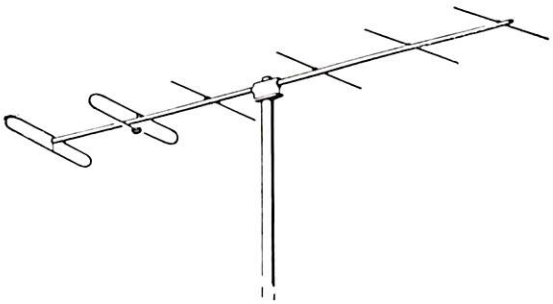
Clearly, the aerial terminal impedance can be made almost any value by this technique. For instance, for a reduced impedance, the driven element would be made shorter (capacitive) and the non-driven one longer (inductive). Whereas a half-wave dipole behaves as a series inductive/capacitive (L/C) tuned circuit, the "Tru-Match" system is akin to a parallel tuned circuit. The arrangement not only aids matching but also facilitates bandwidth requirements of television aerials.

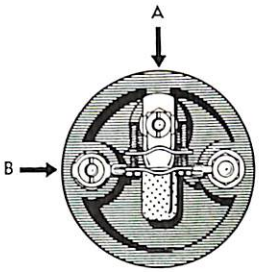
Other Band I aerials that are in use, though may not be in current manufacture, include the "X" aerial, illustrated in Fig. 3.15, "loop" and "square" configurations, and various other designs.

The "X" aerial is really a modified "H" aerial, both the dipole and the reflector (or director) being bent in the centre to form the "X" configuration. Some "square" aerials use two half-wave sections arranged to form a symmetrical square, an insulator being used for connecting the feeder. The "loop" aerial may be of similar design, but the elements are formed into a circle instead of a square. Corresponding parasitic elements may also be adopted.

AERIALS FOR TELEVISION IN BAND III

Band III aerials are really scaled-down versions of their Band I counterparts, but owing to the smaller dimensions of the elements, a greater number of elements can be employed for a given aerial bulk. More elements are often required on a Band III aerial than on a Band I counterpart because the smaller dipole of the former delivers a signal of lower strength to the feeder from a signal of given field strength than the longer dipole of the latter. However, it must be noted that the field strength of the higher frequency transmissions is stronger than that of the lower frequency transmissions when the trans-





(Left) FIG. 3.16. *Six-element Band III aerial. This features a folded dipole, folded reflector for enhanced bandwidth and four directors for high gain. (J-Beam Aerials Ltd.)* (Right) FIG. 3.17. *The appearance of the J-Beam patented inverse balun with the top cover removed. This is actually fitted at the dipole terminals, and forms the junction box to the feeder. A is the outer conductor to clip and B the inner conductor.*

mitters radiate equal power. This is explained by the field strength expression in Chapter 1, page 26.

Band III is used exclusively for television, and is divided into eight 5 MHz channels, shown in Table 3.4. (Re-engineering for 625 lines would result in fewer channels.) As in Band I, the signals may be either vertically or horizontally polarized, depending on the transmitter channel number and its location, to minimize the possibility of co-channel interference.

Owing to the extensive use of parasitic elements, some method is adopted to step-up the centre impedance of the dipole, and some Band III aerials also employ a balun. There are various arrangements of dipole, reflector and directors according to the directivity and gain requirements.

An interesting Band III aerial with a folded *reflector*, in addition to the folded dipole, is shown in Fig. 3.16. The Inverse Balun used with this is shown in Fig. 3.17.

The outline of an interesting Band III aerial is shown in Fig. 3.18. This uses a folded dipole at the front followed by ten directors. This aerial

Table 3.4

405-LINE TELEVISION CHANNELS IN BAND III

Channel No.	*Sound (MHz)*	*Vision (MHz)*
6	176·25	179·75
7	181·25	184·75
8	186·25	189·75
9	191·25	194·75
10	196·25	199·75
11	201·25	204·75
12	206·25	209·75
13	211·25	214·75

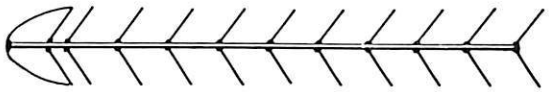


FIG. 3.18. *Fishbone aerial in which the first element on the left is a special folded dipole. This is followed by ten directors.* (*C-Aerials Ltd.*)

has a high forward gain and large front/back ratio (the latter implying that the rear rejection is high).

COMBINED BAND I/BAND III AERIALS

Many designs of composite aerials suitable for operating in both Bands I and III have been evolved, the idea being to minimize the amount of metalwork exposed to the skyline. The development of this type of aerial has followed the build-up of Band III stations over the country, and now that most of the country is fairly well catered for on both Bands I and III, composite aerials are less complicated than they used to be.

An early idea took the form of add-on adaptors to make a Band I aerial responsive also to the local Band III channel. Some typical examples of this principle are illustrated in Fig. 3.19. At (*a*) and (*b*) two "V" elements with dimensions to suit the Band III channel are shown clipped to the Band I dipole. At (*c*) a Band III clip-on reflector is also used. This method of obtaining two-band operation has its limitations, but it does serve in areas of reasonable signal strength and low interference.

At the Band I frequency, the add-on Band III elements "look" like a very

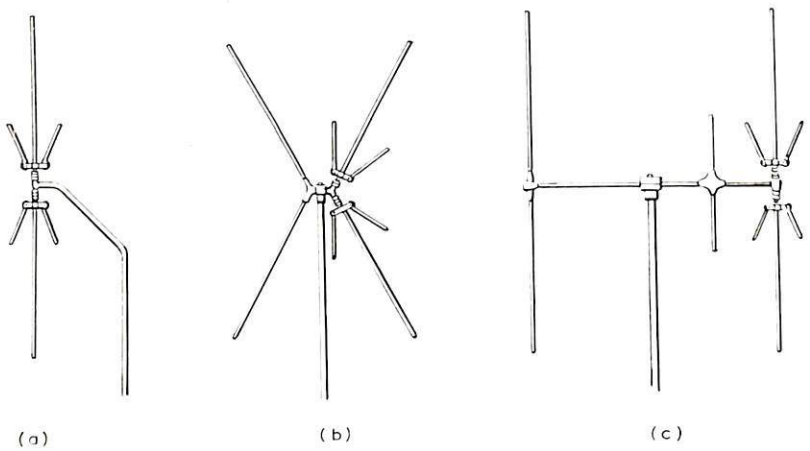


FIG. 3.19. *Showing the use of clip-on Band III elements to make a Band I aerial responsive also to Band III signals of the local channel. At* (a) *and* (b) *the elements are clipped on to the dipole and at* (c) *a reflector clip-on element is also used.* (*Antiference Ltd.*)

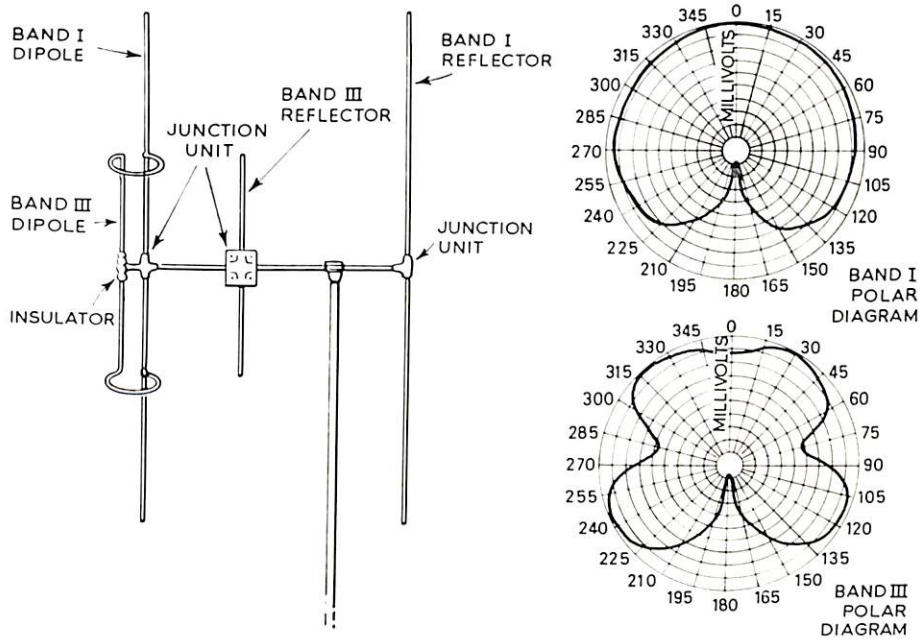


FIG. 3.20. *A true dual-band aerial and its polar diagrams for Band I and Band III.* (*Telerection Ltd.*)

high impedance to the Band I termination and thus detract little from the performance of the Band I aerial. Conversely, at the Band III frequency, the add-on elements load the feeder and the parallel Band I dipole "looks" like a high impedance. It will be appreciated that the performance of this arrangement must be something of a compromise. The resulting polar diagrams on the two bands are also unpredictable.

A follow-up of this arrangement is the true "dual band" aerial, and one example of this is shown in Fig. 3.20 along with the Band I and Band III polar diagrams. These show that the Band I section of the aerial has the heart-shaped polar diagram of the true quarter-wavelength "H" aerial, while the Band III section has acceptance at four corners with minimum response at the rear. The four-corner response of the Band III section is desirable in some instances where the aerial is to be used for Band I and Band III transmissions which do not originate at the same site. The Band I aerial can then be set up for maximum response and the aerial rotated first one side and then the other of this orientation until maximum Band III pickup is also obtained. Theoretically, this adjustment should not interfere unduly with the Band I pickup, as the Band I polar diagram reveals a very wide angle of acceptance.

Some composite aerials are virtually two aerials in one, arranged so that they can be orientated independently. They are coupled together either by a

matching stub or transformer or by a filter, such as a diplexer, described in Chapter 4.

Wideband Band III Requirement. There is a growing need for Band III aerials that will themselves respond without sideband clipping to two or more Band III channels. Reasons for this are that some areas in Great Britain are now able to receive two ITV programmes (these have always been radiated on Band III channels) and that the BBC is now using Band III for some of its programmes. In areas where the BBC is adopting Band III channels, these are separated at least by three and up to six channels from the channels used by ITV in the local area. With conventional aerials this means that one or other of the stations is discriminated against. Thus, for balanced reception either two (or more) separate Band III aerials are needed, filtered into a single down-lead, or a single, wideband Band III aerial.

TELEVISION AERIALS FOR BANDS IV AND V

Band IV is from 470 to 582 MHz, divided into fourteen 8 MHz channels, and Band V is from 614 to 854 MHz, divided into thirty 8 MHz channels. The former band gives channels 21 to 34 inclusive and the latter gives channels 39 to 68 inclusive. Channels 35, 36, 37 and 38 are not yet used in Great Britain for television. The channels and their frequencies in Bands IV and V are given in Tables 3.5 and 3.6 respectively.

In Great Britain there will be an eventual four programmes available in a region. Thus, each region is allotted a group of four u.h.f. channels. These are not adjacent channels but they are arranged in the majority of groups to embrace an overall bandwidth of 88 MHz. Actually, the channel numbers over the country have been very carefully worked out for the minimum of

Table 3.5

TELEVISION CHANNELS IN BAND IV

Channel No.	*Frequencies (MHz)*
21	470—478
22	478—486
23	486—494
24	494—502
25	502—510
26	510—518
27	518—526
28	526—534
29	534—542
30	542—550
31	550—558
32	558—566
33	566—574
34	574—582

interference with regard to radiation from sets and their spurious acceptance responses, such as "image" acceptance (i.e., "second channel") and so forth.

The overall frequency spectrum occupied by some of the regional channel groups is greater than 88 MHz. The requirement, then, is for an aerial system that had a bandwidth sufficient to cater for the four channels of any group, Some early u.h.f. aerials were peaked to one specific frequency; that is. to the frequency corresponding to the first operational channel in a given area. While these aerials work very well on that particular channel, their performance is somewhat impaired (in some cases considerably impaired) when brought into operation on the remaining three channels of the group. The solution here is either to replace the aerial with a correct wideband type or to use a second aerial responsive to the remaining three channels, leaving the original aerial working on the first channel, and then coupling the two aerials to a common downlead through a filter.

This latter is a messy and probably "lossy" solution to the problem. By far the best idea is to replace the "sub-standard" aerial with one of correct bandwidth. Fortunately, this problem is unlikely to be very widespread, for an agreement is now in force whereby aerial manufacturers ensure that their u.h.f. aerials have sufficient bandwidth adequately to embrace the frequency spectrum occupied by the four channels of a group. The same agreement applies to aerial equipment, such as filters, amplifiers and so forth. The gain, impedance, directivity and other characteristics of the aerial and associated equipment need to remain reasonably consistent over the whole bandwidth. So far as aerials are concerned, this is achieved by very careful design in terms of length and spacing of the dipole and parasitic elements.

Table 3.6

TELEVISION CHANNELS IN BAND V

Channel No.	*Frequencies (MHz)*	*Channel No.*	*Frequencies (MHz)*
39	614—622	54	734—742
40	622—630	55	742—750
41	630—638	56	750—758
42	638—646	57	758—766
43	646—654	58	766—774
44	654—662	59	774—782
45	662—670	60	782—790
46	670—678	61	790—798
47	678—686	62	798—806
48	686—694	63	806—814
49	694—702	64	814—822
50	702—710	65	822—830
51	710—718	66	830—838
52	718—726	67	838—846
53	726—734	68	846—854

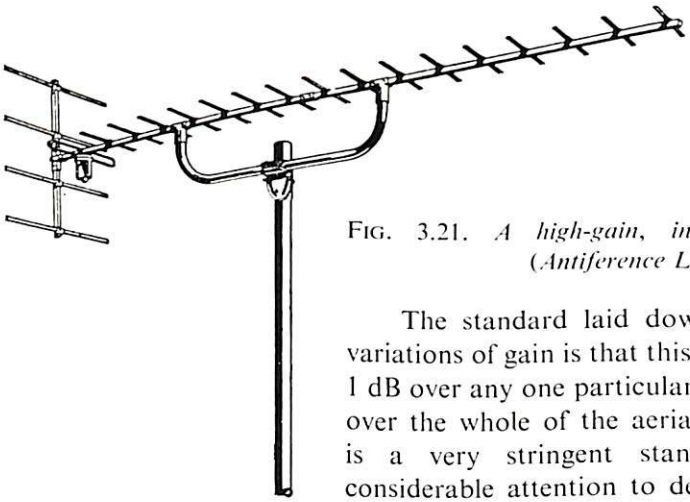


FIG. 3.21. *A high-gain, in-line u.h.f. aerial. (Antiference Ltd.)*

The standard laid down with regard to variations of gain is that this should not exceed 1 dB over any one particular channel and 3 dB over the whole of the aerial bandwidth. This is a very stringent standard, demanding considerable attention to design detail.

A u.h.f. wideband aerial can only be successfully designed as a complete entity, and this means that the reflector system and directors need to be "tailored" in terms of length and spacing to secure the flat response requirements. For example, an aerial with eleven directors may call for a somewhat different reflector system design from a similar Yagi with only four directors. Conversely, a change in number of elements on a reflector system may demand a change in length and/or in spacing of the directors to preserve the wideband characteristics.

Manufacturers design their u.h.f. aerials in channel groups for ease of handling. There are five groups (A, B, C, D, E) covering channels 21 to 34, 39 to 51, 50 to 66, 49 to 68 and 39 to 68, colour coded red, yellow, green, blue and brown respectively. The areas which these groups will serve can be discovered from Table 3.7, which gives the proposed locations of the u.h.f. stations in Great Britain and their associated channel numbers.

Most u.h.f. television aerials are based on the Yagi principle, and owing to the small size of the elements a far greater number of them can be used advantageously than on Band I or Band III arrays. Sixteen or more directors are employed on some arrays and it is commonplace to use more than just a single element for the reflector. Fig. 3.21 illustrates such an array. This has a reflector system composed of four elements, a folded dipole with balun and 16 directors.

Some arrays use a wire mesh type of reflector instead of rod elements. Others may use just a single rod or two rods. Aerials for local reception may have one, two or three directors, the number increasing for use in difficult reception areas and in locations towards the edge of the service area. Reception beyond the service area demands arrays with a great multiplicity of elements. More is said about the choice of aerial in Chapter 4.

Design Trends. An interesting example of a new u.h.f. aerial development is the "Multibeam" by J-Beam Aerials Ltd. This is styled after the earlier "Parabeam", referred to on page 221, which has a skeleton slot radiator and reflector. However, while ordinary rods are employed for the directors of the Parabeam, the directors of the Multibeam are specially tailored with four prongs on them (see Fig. 3.22(*a*)). Although the aerial comprises a single radiator and reflector system, the prongs on the directors endow the overall array with characteristics similar to those obtained by stacking (see the following section).

Normally this kind of array is composed of a multiplicity of separate in-line arrays, specially matched and phased to yield the expected gain increase and narrowing of the beam angle. With the Multibeam, however, it has been discovered that almost the same effect can be achieved by the employment of a common radiator and reflector of the Parabeam kind when partnered with the four-pronged directors.

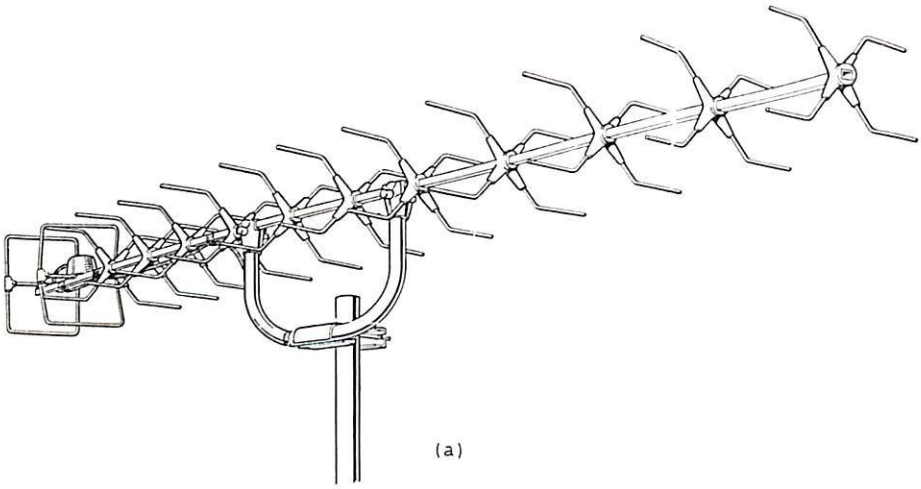
During the development of the system it was discovered that by modifying a Parabeam of ten directors to accommodate ten of the multiple director elements a gain advantage of almost 5 dB could be obtained with no shrinkage of bandwidth, which is almost equivalent to the stacking of *four* Parabeams each of ten ordinary directors!

The modified impedance effects at the radiator terminals due to the action of the multiple director units are countered by the J-Beam "Inverse Balun" and matching device, explained on page 58. It is noteworthy that Model MBM46, whose bandwidth/gain curve is shown in Fig 3.22(*b*), gives a performance equal to a double-eighteen-element Parabeam, yet incorporating only eleven multiple (times four) director elements.

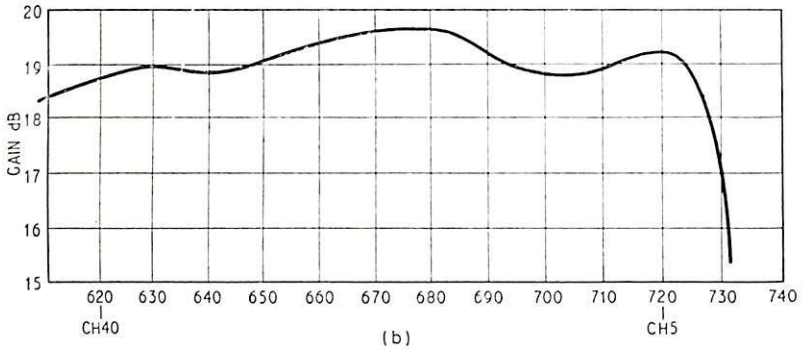
Another interesting development by Antiference, but this time on Band III, is the log-periodic aerial. The aerial looks like an ordinary Yagi design, but is certainly different in basic operation and construction. Each element, in fact, is a separate dipole, the length and spacing of which follows a law of geometric progression, as shown in Fig. 3.23. All the "dipole" elements are connected together in alternating "polarity", and the feeder line making this possible is built into the cross-boom carrying the elements, the effect being that adjacent dipole terminations are staggered, giving the criss-cross effect of Fig. 3.23.

Bandwidth over Band III is provided by the tapering resonance of the dipoles; for example, if the dipole in the middle of the array was the one required for a particular channel, then those behind it would effectively act as reflectors and those in front as directors.

The technique ensures good gain, excellent bandwidth, constant resistive loading to the feeder over the entire spectrum and a stable polar diagram.



(a)



(b)

FIG. 3.22 (a) *New "Multibeam" u.h.f. aerial by J-Beam Aerials Ltd., Model MBM 46. The four-pronged director elements give the effect of array stacking, explained in the text.* (b) *Frequency/gain response of the Multibeam, Model MBM 46. This is composed of the Parabeam radiator and reflector (slot type), the J-Beam "Inverse Balun" and eleven pronged directors.*

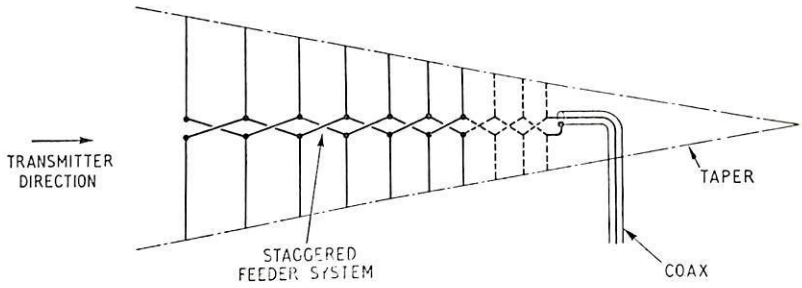


FIG. 3.23. *Principle of the Antiference log-periodic Band III aerial (see text).*

PRACTICAL AERIAL SYSTEMS

STACKED AND BROADSIDE ARRAYS

It has already been intimated that the law of diminishing returns comes into play after a certain number of directors have been added to a Yagi array. To increase both gain and directivity further, therefore, two or more complete Yagi arrays are arranged in stacked or broadside formation.

Fig. 3.24 depicts a broadside array at the top of the pole and a straight Yagi below. These arrays, it will be seen, employ a "mesh" type of reflector. The mechanics of a stacked array are shown in Fig. 3.25. It will be seen that the array can be tilted for optimum positioning.

Stacked and/or broadside arrays are also used for reception in Bands I

Table 3.7

U.H.F. TELEVISION CHANNEL GROUPS

Area	*Channel Groups*				*Area*	*Channel Groups*			
Belfast (Divis)	21	24	27	31	Guildford	40	43	46	50
Caithness	21	24	27	31	Tunbridge Wells	41	44	47	51
Cardiganshire	21	24	27	31	Buchan	41	44	47	51
East Lothian	21	24	27	31	Caernarvonshire	41	44	47	51
Huntingdon	21	24	27	31	Jersey	41	44	47	51
Isle of Wight (Rowridge)	21	24	27	31	Kirkcudbrightshire	41	44	47	51
West Yorks	21	24	27	31	Londonderry	41	44	47	51
Argyllshire	22	25	28	32	South Yorks (Emley Moor)	41	44	47	51
Cumberland	22	25	28	32	South Wales (Wenvoe)	41	44	47	51
East Cornwall	22	25	28	32	Suffolk	41	44	47	51
East Lincs	22	25	28	32	West Cornwall	41	44	47	51
Fermanagh	22	25	28	32	Guernsey	48	52	54	56
Herefordshire	22	25	28	32	East Sussex	49	52	64	67
Kincardine (Durris)	22	25	28	32	South-east Kent (Dover)	50	53	56	66
Ayrshire	23	26	29	33	Anglesey (Llanddona)	53	57	60	63
Banff	23	26	29	33	Carmarthenshire	53	57	60	63
East Devon	23	26	29	33	East Yorks	53	57	60	63
Lewis	23	26	29	33	Northamptonshire	53	57	60	63
London (Crystal Palace)	23	26	30	33	Perthshire	53	57	60	63
North Yorks	23	26	29	33	South Devon	53	57	60	63
Staffordshire	23	26	29	33	Wigtown	53	57	60	63
Isle of Man	30	34	48	52	Reigate	53	57	60	63
Shetland	32	34	45	49	Hertford	54	58	61	64
Flintshire	39	42	45	49	Armagh	54	58	61	64
Hampshire	39	42	45	66	Bristol	54	58	61	64
Inverness	39	42	45	49	Dumbarton	54	58	61	64
Northumberland	39	42	45	49	Durham (Pontop Pike)	54	58	61	64
B'ham (Stn. Coldfield)	40	43	46	50	Nottinghamshire	54	58	61	64
Dorset	40	43	46	50	West Sussex	55	58	61	68
Lanarkshire (Black Hill)	40	43	46	50	Norfolk (Talconeston)	55	59	62	65
North Kent	40	43	46	65	North Antrim	55	59	62	65
North Lancs	40	43	46	56	North Devon	55	59	62	65
Orkney	40	43	46	50	Selkirkshire	55	59	62	65
Pembrokeshire	40	43	46	50	South Lancs (Winter Hill)	55	59	62	65

FIG. 3.24. *U.h.f. Yagi aerials under test.*

and III (and infrequently in Band II). Pioneered by J-Beam Aerials Ltd. is the skeleton slot aerial (see page 61). A broadside array coupled by the slot dipole is illustrated in Fig. 3.26. This gives a gain of 16 dB on a Band III channel over the gain of an ordinary dipole. The slot facilitates the coupling and the phasing of the two linear sections, each of which consists of a reflector and four directors, with the slot dipole as the active element. It will be seen that the feeder is connected to the centre of each side of the slot by a "Y" matching section.

Stacked and broadside configurations are not so much used now on Bands I, II and III, but they are often highly desirable on the u.h.f. bands. Theoretically, the overall gain of two correctly phased and coupled arrays of the same type is about 3 dB above the gain of one of the aerials by itself. However, this may not always follow in practice because the forward gain of the individual aerials is modified by the presence of its partnering aerial and

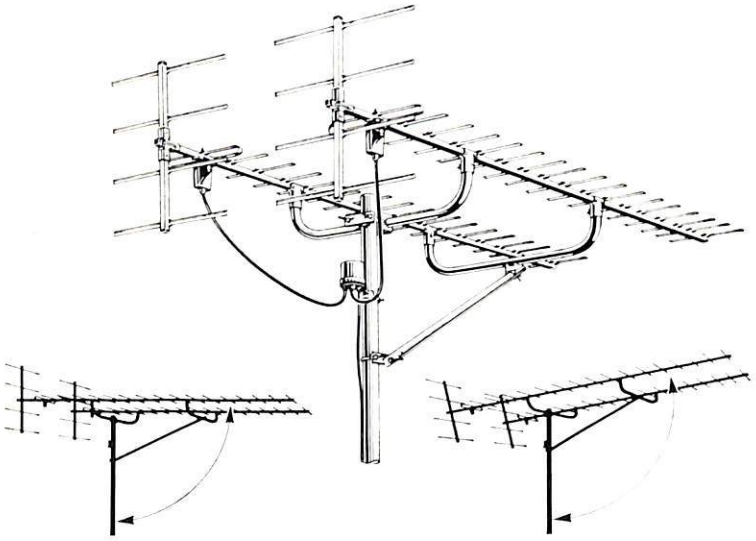
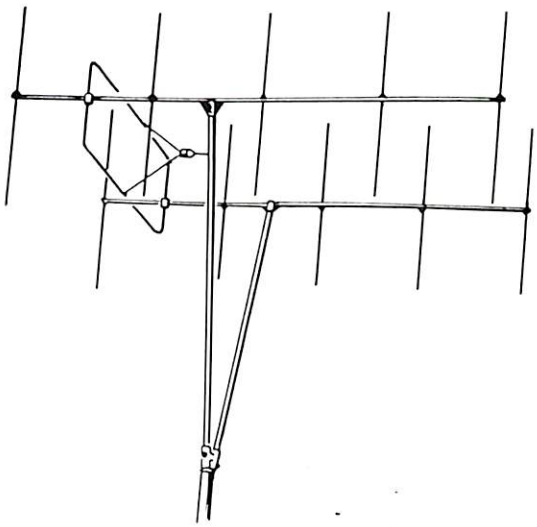


FIG. 3.25. *Aerials in broadside array. The two small pictures beneath show how this array can be tilted as required. (Antiference Ltd.)*



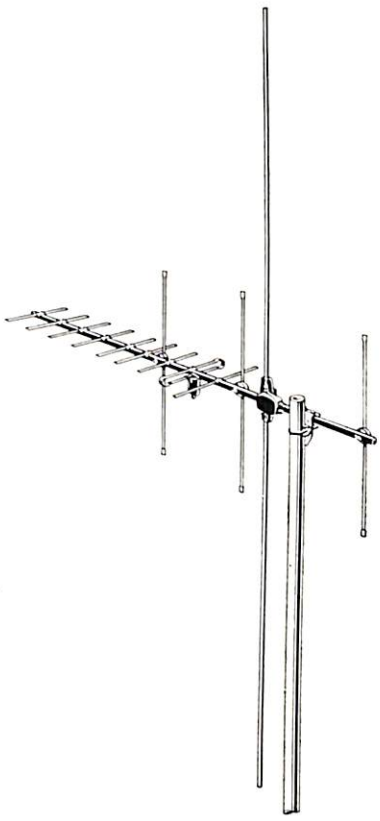


FIG. 3.26. *The Double-Six Slot aerial (J-Beam Aerials Ltd.). The slot principle is also retained on some of this firm's u.h.f. aerials.* (Right) FIG. 3.27. *An "all-band" aerial. (Antiference Ltd.)*

because of possible losses and mismatch effects in the coupling of the two aerials to a common downlead.

One way of coupling two aerials in broadside formation is by spacing them by half a wavelength and then joining their dipoles to a common downlead at a connecting box through *equal lengths* of coaxial cable. This technique ensures that the two signals are added in phase, thereby delivering their sum to the common feeder. Commercial aerials of this kind, however, often feature carefully designed matching sections of rigid metal, rather than flexible feeder. The idea is to arrange the signals to add in phase while preserving the aerial-to-feeder matching.

Some broadside arrays are spaced wider than half a wavelength, but then the phasing is achieved in the interconnecting transmission lines. When aerials are placed side by side the forward gain is increased, unwanted lobes in the polar diagram are cancelled and the matching is often enhanced.

Stacked arrays (one aerial above the other) give an improvement in vertical polar diagram, the horizontal response being little altered.

For long-distance reception, four Yagi aerials are sometimes arranged in a vertical horizontal stack formation, in the form of a "box".

ALL-BAND AERIALS

In areas of reasonable signal strength from all transmitters it is possible to employ a single aerial system that is designed to respond to television signals in Bands I, III and u.h.f. An aerial employing this technique and shown in Fig. 3.27 is the "Uniray" by Antiference. It incorporates a Band I dipole (the long element) which is "electronically coupled" to an element which resonates at the required Band III channel, this acting really as the Band III dipole in conjunction with a reflector and director. These are the three short, vertical elements. The u.h.f. section consists of a nine-element Yagi array made up of a folded dipole with balun connection, a single rod reflector and seven directors. As all-band television receivers have separate inputs for the v.h.f. and u.h.f. signals, two downleads are used, one for v.h.f. and the other for u.h.f.

It will be seen that the Band I and III sections are set for vertical polarization while the u.h.f. section is set for horizontal polarization. This is because the main u.h.f. stations radiate horizontally polarized signals, while most of the main v.h.f. stations radiate vertically polarized signals. The v.h.f. sections, of course, would have to be arranged horizontally for use on channels that adopt horizontally polarized signals. U.h.f. relay stations use vertical polarization in some locations.

Another interesting aerial is shown in Fig. 3.28. This is a semi-broadband array (less Band I section) with five elements on the v.h.f. band (for BBC1 and ITV) and twelve elements on the u.h.f. band. There are variants of this aerial, giving three v.h.f. elements plus twelve u.h.f. elements, or three v.h.f. elements plus six u.h.f. elements.

Other aerial manufacturers have similar aerials available, but it is not possible to mention all of them here. Readers interested in securing all the latest television aerial statistics should consult a television dealer.

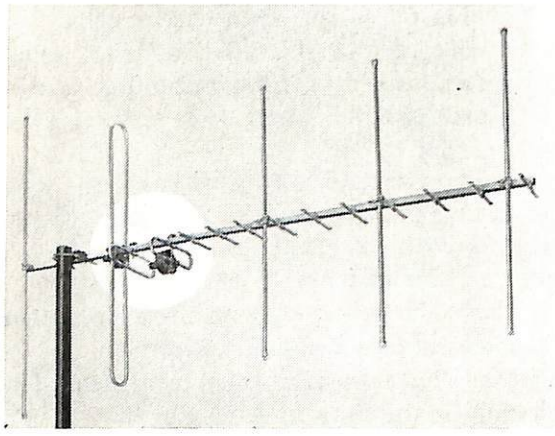
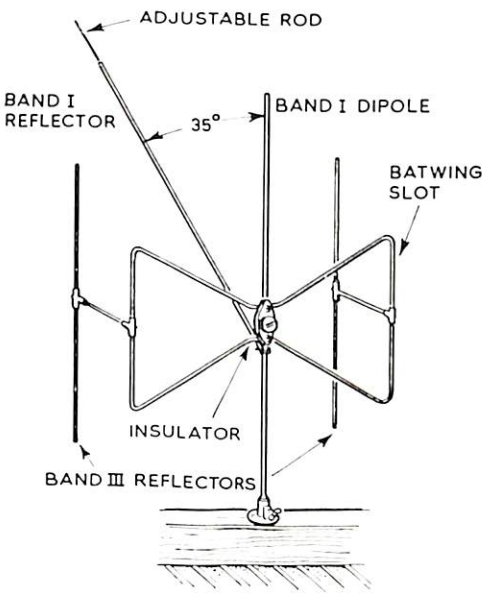
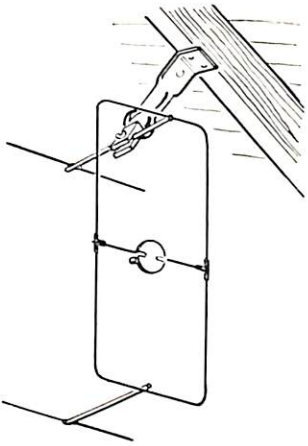


FIG. 3.28. *A semi-wideband aerial. The u.h.f. section incorporates a folded reflector, a folded dipole with the J-Beam Inverse Balun (shown highlighted), and ten directors. (J-Beam Aerials Ltd.)*





(Left) FIG. 3.29. *An unusual all-band attic-mounted aerial.* (*J-Beam Aerials Ltd.*)
(Right) FIG. 3.30. *This u.h.f. attic-mounted aerial features a skeleton slot.* (*J-Beam Aerials Ltd.*)

ATTIC AND ROOM AERIALS

As the whole of the country becomes embraced by television signals of high field strength, so it becomes possible to utilize aerials of less complexity while preserving good quality reception of low interference content. In areas of high signal field, therefore, simple attic or room aerials can sometimes be used to good account.

Fig. 3.29 shows a Band I/III array for attic use and also identifies the various elements. The Band III dipole is a skeleton slot in the shape of a batwing for reactance compensation. This is coupled at the low impedance point to the centre of a Band I rod dipole. The Band III reflectors are set off on small booms each side of the slot, while the Band I reflector is in the form of an adjustable rod, allowing the use of the array in locations of limited height. This element is also adjusted in length to suit the required Band I channel.

Another aerial from this range is a skeleton slot with reflectors for the u.h.f. bands. This is for mounting on a cross member in the roof space, as shown in Fig. 3.30. A ball-joint coupling allows the aerial easily to be orientated for the best pickup.

A more substantial type of attic u.h.f. aerial is illustrated in Fig. 3.31. This employs a folded dipole, folded reflector and eight directors. The dipole

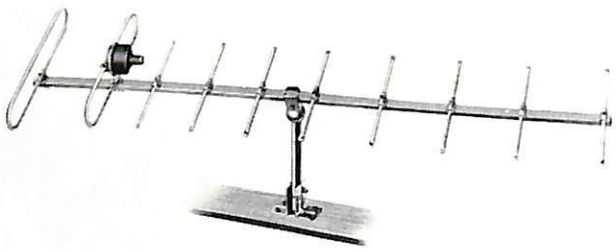


FIG. 3.31. *Attic-mounted u.h.f. Yagi array with folded dipole and folded reflector. (J-Beam Aerials Ltd.)*

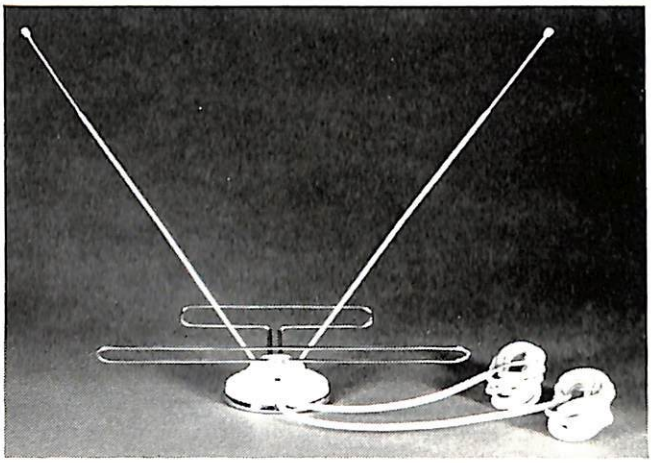


FIG. 3.32. *All-band set-top aerial. (Antiference Ltd.)*

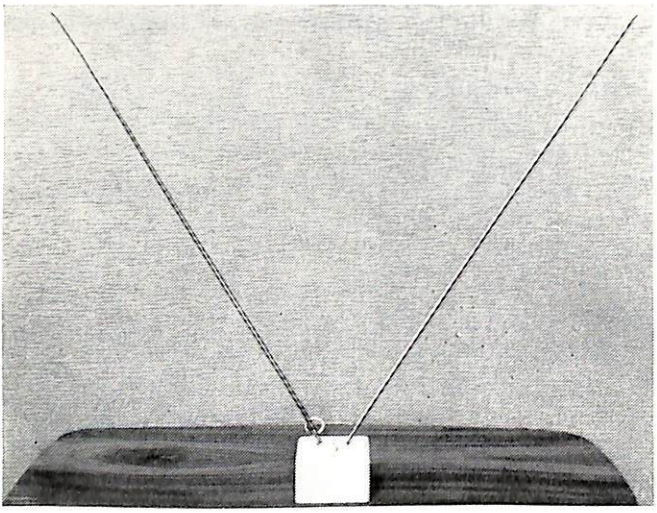


FIG. 3.33. *A prototype v.h.f. set-top aerial and base-mounted transistor amplifier, operated from an internal battery.*

can be coupled to the downlead through the J-Beam Inverse Balun. Again, a ball joint allows for easy orientation.

Aerials for use in the room by the television set include various designs in picture frames. One incorporates a u.h.f. skeleton slot and a pull-out rod at the top of the frame for reception of the Band I and Band III signals. Also popular and reasonably satisfactory in good signal areas is the set-top aerial. An example of this type is shown in Fig. 3.32. This aerial embraces all the v.h.f. channels in Bands I, II and III and all the u.h.f. channels in Bands IV and V. The active elements are folded dipoles and separate leads are used for the v.h.f. and the u.h.f. sections.

An early prototype set-top aerial incorporating an inbuilt transistor amplifier and battery for signal boosting, developed by the author, is shown in Fig. 3.33. This employs two telescopic rod elements terminated on ball joints for adjustment. The press-switch on top of the base switches the aerial on and off.

A further development of this aerial is shown in Fig. 3.34. This incorporates a dual-band (Bands I and III) transistor amplifier and 9-volt battery, but features just a single rod. The other element of the dual-band aerial system is made up of the outer screen of the coaxial cable feeding the signal from the aerial to the set. The picture on the set is Band III over a distance of thirty miles.

An experimental set-top u.h.f. slot aerial designed by the author is shown in Fig. 3.35. This is built into a wooden box with a plastic or cloth front covering, as shown at (*b*). The slot elements of the aerial are made of plywood covered in tin foil, there being a slot dipole, reflector and director. The method used to secure a low-impedance, unbalanced feed from the slot dipole to the coaxial cable can be seen at (*a*). A wire is run slightly off centre down the length of the slot and the connection to the feeder is made at the correct impedance point. Details for building this aerial were published in the June 1965 issue of *Practical Television*.

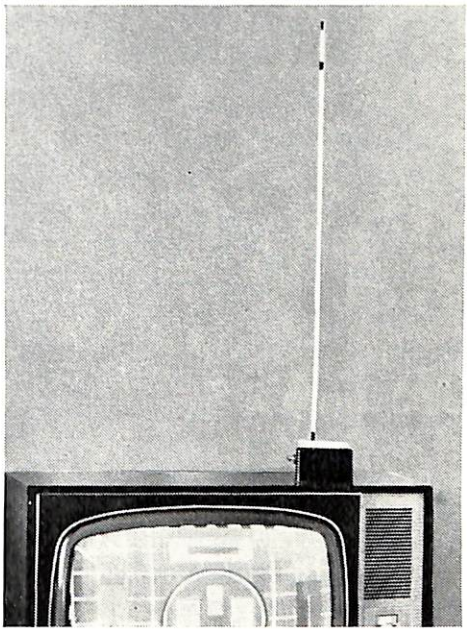
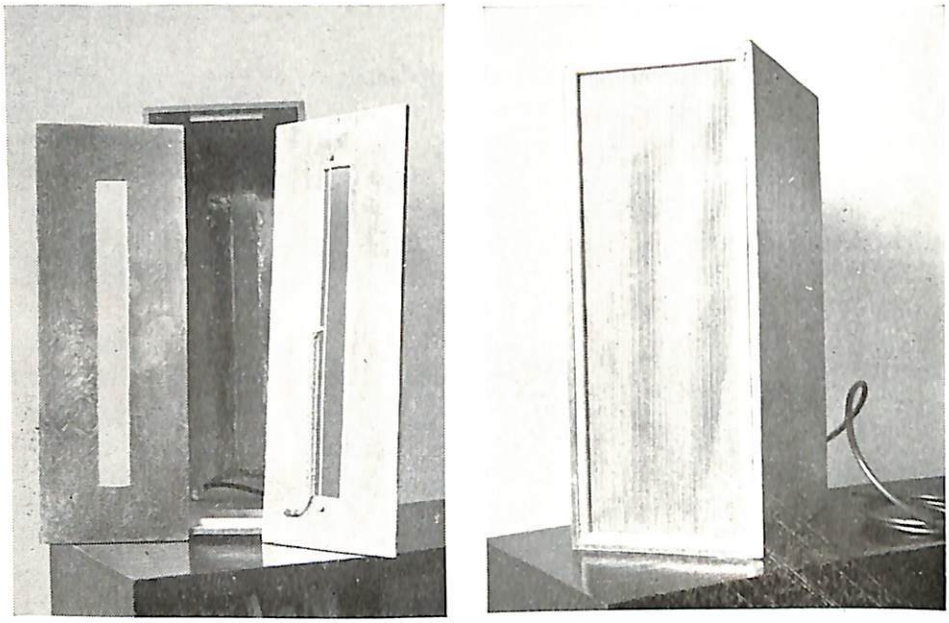


FIG. 3.34. *The King powered set-top aerial (Transistor Devices Ltd.)*



(a) (b)

FIG. 3.35. *An experimental set-top aerial designed by the author. At* (a) *is shown the spectally loaded dipole, the reflector and director, while at* (b) *is the aerial as it appears ready for operation.*

CAR AERIALS

A brief mention must be made of car aerials for radio reception. These differ, of course, from the type of aerial used for communications applications, as this type of aerial is a resonant device in grounded quarter-wave mode, while the ordinary car radio aerial is generally a non-resonant collector for m.f. signals.

Owing to the relatively short length of the car radio aerial and the consequent weak signal that appears at the end of its downlead, the car radio has generally to be of greater sensitivity than a domestic set that can operate on a much longer aerial wire or ferrite rod aerial. This leads to signal/interference problems, aggravated by the strong interfering field from the car's electrical system, particularly the ignition system.

The maximum level of ignition interference is inside the metal body of the car, and to avoid excessive pickup of this the car radio and the downlead from the aerial to the set's aerial socket have to be thoroughly screened. The aerial downlead is thus of a screened cable, such as coaxial cable, and the outer conductor (screen) of this and the screen round the radio itself are

bonded to the car metalwork. When properly set up in this manner, only the aerial is responsive to signal, the downlead and set picking up very little, if any, signal (or interference) direct. The signal/interference ratio is further improved by the use of interference suppressors on the ignition system (often one in each plug lead) and on the dynamo, windscreen wiper motor and so forth.

Most car radio aerials are of the telescopic type and need little description. Their position on the car, however, is important. They should be kept as far away from the engine as possible, using the whole body of the car to screen the aerial from the engine. Aerials are now being mounted on the rear bumper and this would appear to be a good idea on front engine cars, provided they can be fitted in this position safely. Theoretically, the aerial should be fitted to the front of rear engine cars by the same token. In many instances, however, the aerial is fitted to the front of the car, often on the front wing, irrespective of position of the engine.

It is interesting to see how car radio aerials can themselves be "resonated" to greatly enhance the pickup sensitivity at a particular frequency. We have already learnt that an aerial which is too short for resonance will encounter a capacitive reactance and that this can be overcome by the addition of series inductance, which neutralizes the capacitance and thus gives resonance.

This principle can be adopted so far as car radio aerials are concerned. The idea is to "load" the aerial with a suitable value of inductance and then adjust the length of the telescopic aerial for resonance at the required frequency. In practice, the tuning is relatively flat, so that when the aerial is brought towards resonance on, say, the medium wave band, sensitivity is enhanced not only at the tuned frequency but also over a range of frequencies either side of resonance.

There is at least one commercial aerial tuning unit based on this principle for ordinary car radio aerials. The aerial is cut near the base and then joined together through the unit, clamp screws being fitted at each end to facilitate this operation. The principle is also used extensively for transmitting, so that a rod aerial installation of limited length can be "tuned" to load a transmitter at a frequency well below the resonant frequency of the aerial

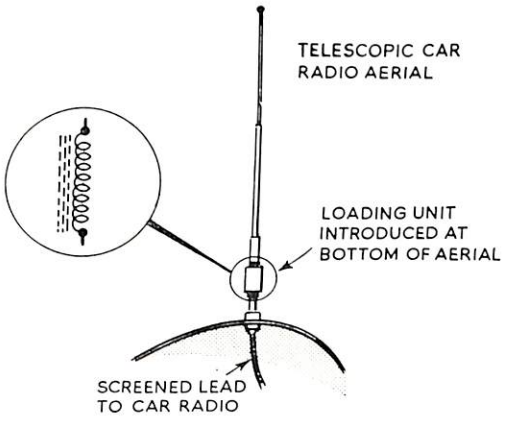


FIG. 3.36. *Loading unit or "resonator" used on a car radio aerial or transmitting aerial.*

itself. The method of installing a loading unit is illustrated in Fig. 3.36.

For readers who wish to experiment with tuning a car radio aerial in this way, the following information will prove of interest. To tune over the medium wave band, a "loading coil" can be wound on a 4 in. length of ferrite rod of $\frac{3}{8}$ in. diameter, using 120 turns, close spaced, of 20 s.w.g. enamel-covered wire. When connected in the aerial circuit, as shown in Fig. 3.36, the length of the telescopic car radio aerial should be adjusted for maximum sensitivity with the set tuned to a weak medium wave station at the high-frequency end of the band.

TRANSISTOR PORTABLES IN CARS

The trend now is to use transistor portable radios in cars. This kind of set is not really very well suited to this application because its internal ferrite rod aerial not only makes it directional, causing fading each time the direction of the car is changed, but it is also very sensitive to the ignition interference inside the car, even though the engine may be adequately suppressed for an ordinary car radio.

This trouble can be reduced to some extent by feeding signal to the radio from an aerial outside the car. Clip-on type aerials are available for this purpose and the majority of manufacturers of transistor portables now fit a socket for the connection of such an aerial. However, because the efficiency of the ferrite rod aerial in the portable is greater than that of a short car-type aerial and because the coupling efficiency between this aerial and the transistor portable is poor, improvement to reception by this technique is often very

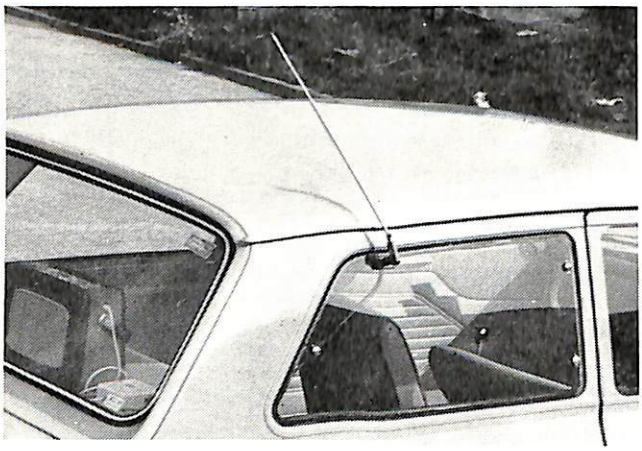


FIG. 3.37. *The King Karad booster in operation in a car. This is connected between a simple clip-on car aerial and the aerial socket of the transistor portable radio. The action of this system is fully explained in the text.*

marginal, and in some cases the connection of the car-type aerial appears to have no effect at all, ignition interference and fading still being very troublesome.

The author has been engaged in investigating this problem over the years and has devised a wideband transistor booster and aerial matching device, called the *King Karad* (British Patent No. 1047484). This is completely self-contained and battery operated and connects between the car-type aerial and the transistor set.

It works as follows. The weak signals from the outside aerial are amplified by about ten times, and these signals are then transferred at good efficiency to the transistor set aerial socket. They thus outweigh the signals picked up by the ferrite rod aerial, effectively making this aerial inactive. The directivity effect of the ferrite rod aerial is cancelled completely, and the boosted signals cause the ferrite rod sensitivity to be greatly reduced by the set's a.g.c. (automatic gain control) action. The ferrite rod aerial then responds very little to the internal ignition interference.

In other words, the signal/interference performance of the transistor portable used in the car is greatly improved, and while the overall results are probably below those expected from a proper car radio, the arrangement does allow the use of a transistor portable in a vehicle with good success. The King Karad in action is shown in Fig. 3.37. It can be seen plugged into the transistor portable. Into it is plugged the lead from the clip-on aerial of the kind that are made for use with transistor sets.

CHAPTER 4

Aerial Choice, Erection and Maintenance

THE choice of any aerial system is governed by the prevailing signal conditions, by the location and by the requirements and the space available for its erection.

For transmitting and serious short-wave listening, aerial systems in advance of those required for average domestic reception are required. Transmitting aerials are often cut to have some specific relationship to the frequency of the signal and they may be designed to concentrate the signals in one particular direction. This book is not intended to explore these highly specialized aerial systems, however. While the earlier chapters have touched on the basic principles of such aerials, since many of them are common to aerials in general, from now on we shall be considering aerials and equipment used chiefly for domestic radio and television sets.

For ordinary reception of long and medium wave transmissions any reasonable length of wire works well with the modern receiver of high sensitivity. The biggest problem with sketchy aerials is not so much lack of signal pickup, but the response to interference, especially on the long wave band. Electrical interference fields are much in evidence in built-up areas due to the widespread use of electrical domestic appliances. Television receivers, too, can emit signals from their line timebases which manifest as a high-pitched whistle superimposed on the Radio 2 programme of the BBC or other long-wave transmissions.

On the medium wave band after dark serious listening is now almost impossible due to the very bad crowding of transmissions, especially towards the high-frequency end of the band. Stations beaming popular music into Great Britain are adding to the general chaos of the medium-wave ether-ways. The situation has got so bad that it is totally impossible to do anything about it from the aspect of interference elimination at the set. There is very little point, then, in erecting highly efficient medium-wave aerials. These would only make matters worse for the listener.

Some degree of alleviation is offered by the ferrite rod aerial, for it is

often possible to orientate such an aerial carefully so as to push a badly interfering station somewhat into the background while maintaining sufficient pickup of the wanted transmission.

Nevertheless, the bandwidth of long- and medium-wave sets has to be considerably restricted to provide selectivity for even mediocre reception, and this, of course, impairs the audio quality of the transmissions. The net result is that audio frequencies are cut badly above about 5,000 or 6,000 Hz, even in the best of medium-frequency sets, giving poor reproduction. If the bandwidth is extended, as soon as dusk falls at least one interfering station is heard on the wanted programme.

All these problems are overcome by the use of v.h.f. for regional broadcast reception. The three (or more) programmes of the BBC are transmitted simultaneously on Band II, using frequency modulation (f.m.) instead of the amplitude modulation (a.m.) of the medium-frequency transmissions. Extremely good reception is possible in almost all parts of Great Britain, since the whole country is now served by high, medium and low power v.h.f. f.m. transmitters (local-town ones, too).

The f.m. system also endows receivers with an immunity against interfering signals generally, since most of these are amplitude modulated and a correctly designed f.m. set should be almost completely insensitive to a.m. signals. Then there is the f.m. "capture effect" which is a further aid towards interference-free reception, this being an effect whereby only the stronger of two signals on or near the same frequency takes control of the set, the weaker signal causing no response at all. Readers interested in the practical aspects of the f.m. system of broadcasting are referred to the author's *FM Radio Servicing Handbook*.

Nevertheless, to secure full advantage of the f.m. system of broadcasting, an f.m. receiver should be fed with a signal of the highest strength possible, and one which is not particularly troubled with components of interference. In built-up areas close to an f.m. station a simple indoor or roof-space kind of aerial is generally adequate, even at main road locations. This is composed of a simple dipole fed to the set through coaxial downlead (feeder).

A.M. LIMITING ON F.M.

If the electrical and traffic interference is excessive, attention may have to be paid to reducing the pickup of the interfering signals and increasing the strength of the wanted signals. The a.m.-limiting action in the receiver is achieved partly by the nature of the f.m. detector and partly by the inclusion of an amplitude-limiting circuit in the i.f. channel. These circuits work successfully only when the wanted signal rises above a certain level. Generally, the stronger the wanted signal, the greater the amplitude limiting effect. This means that a set may operate without undue disturbance even in an area of

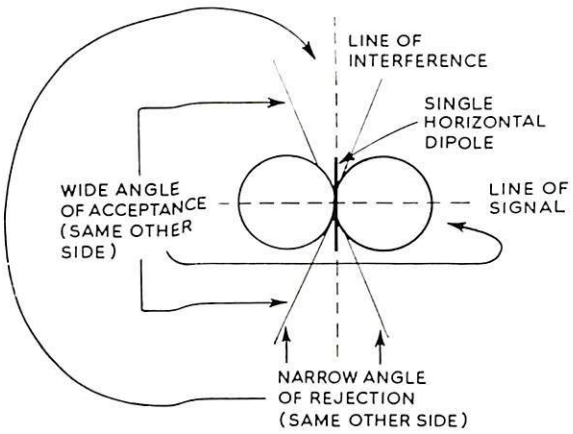


FIG. 4.1. *A horizontal dipole is best orientated for the least interference pickup in the case shown here because of the small angle of rejection and the much larger angle of acceptance.*

heavy interference field, provided the wanted signal pushes the set well into amplitude limiting. The same level of interference field, but a weaker wanted signal field, would be likely to make it almost impossible to use the same set because of heavy interference manifestations.

It will be recalled that a horizontally disposed dipole is bi-directional. Thus, some measure of interference discrimination is possible if the line of direction of any interference is at an angle of about 90 deg. from the line of direction of the wanted signal. The idea, then, would be carefully to orientate the aerial for minimum interference pickup, as shown in Fig. 4.1. It is virtually impossible with an ordinary dipole to orientate the aerial for maximum signal pickup, owing to the wide angle of acceptance. The angle of rejection, of course, is that much smaller, which is why it is best to orientate for minimum interference, rather than maximum signal. The philosophy here is the same as that relating to the orientation of ferrite rod aerials.

CHOICE OF F.M. AERIAL

In areas outside a ten-mile radius from the station a roof-space "X" or "H" aerial may be needed—that is, an array consisting of a dipole plus a reflector *or* director. There is not much difference between the general performance of a dipole plus reflector and a dipole plus director. Most "H" and "X" f.m. aerials now, in fact, adopt a reflector as distinct from a director.

Where the field strength is down some advantage is gained by the use of a three-element roof-space aerial, provided there is sufficient space to orientate the array for the best possible signal pickup. Normally, however, when the need is for something more elaborate than an "H" or "X" array, an outside chimney- or wall-mounted array should be considered. An aerial mounted outside can pick up almost twice as much signal as a similar type indoor aerial at the same height. This is because the signal can be weakened by passing through the roof or wall of the building, especially in wet weather.

Roof-space or attic f.m. aerials can work quite well up to distances of 35 miles from the station, and over greater distances at lofty receiving sites removed from large buildings and hills.

Outdoor aerials should be used for the best results over signal distances in excess of about 35 miles, and for smaller distances in poor reception areas where the interference field may be high. Under normal or average reception conditions a two-element outdoor aerial can suffice up to 40-50 miles from a high power station, and beyond this distance a three-element array (dipole plus reflector and director) is generally suitable.

Modern high-sensitivity f.m. sets and tuners will work from a signal as low as about 10 μV, but full interference-suppression advantage is not obtained unless the signal can be raised to at least 100 μV, depending upon the type and design of the receiver or tuner. (Aerial requirements for stereo reception are considered in Appendix IV, page 217.)

Many tuners and sets feature a tuning indicator which deflects in some way to show when the tuning is correct. Such an indicator is useful for gleaning some idea of the signal strength from the aerial. For best results the indicator should deflect fully on all the local f.m. stations. Deflection below maximum may still provide very good reception, but it could mean that the signal is insufficiently strong for full amplitude limiting.

It may sometimes happen that even with the best aerial system insufficient signal is available for full amplitude limiting. Under this condition, the use of an f.m. signal booster should be considered. These are dealt with in Chapter 6.

CHOICE OF BAND I TV AERIAL

Over most of Great Britain, the signal field in any area due to a Band I transmission is such that good reception is possible with an aerial no more elaborate, at most, than a dipole plus reflector and director (three-element array). Millions of Band I viewers (Band I carries the BBC 1 programmes on 405 lines) find a simple indoor or outdoor dipole sufficient, either vertically or horizontally mounted depending upon the plane of polarization of the local signals. These aerials work well up to ten or so miles from a powerful station. Towards the limit of this distance, however, they should if possible be erected out of doors. A good position for a simple aerial of this kind is towards the top of the wall of the house facing the station, held off by a wall-mounted bracket.

At distances up to about 30/40 miles from a high-power television station an outdoor "H" or "X" aerial is generally adequate. The chimney stack is a convenient mounting place for this. Beyond about 40/50 miles fringe-area conditions start to obtrude, and a three-element array may be needed to secure that little though important extra signal and to permit maximum discrimination against electrical and multipath interference. Aerial height is

also very important here, for the reasons detailed in Chapter 1. Again, the chimney stack provides a reasonable support for this type of array.

There are now very few areas in Great Britain really in the fringe of a Band I signal field. The relatively weak field that exists at locations between the main high-power stations is countered by low-power and booster stations. The latter are sometimes called "translators" because they receive the weak fringe signals on very elaborate, lofty aerial systems and then retransmit them on a different channel number; the transmitter thus "translates" from one channel to another so as to avoid interference problems. The inside of a BBC translator is shown in Fig. 4.2.

Low-power stations, as distinct from boosters and translators, may receive their programme material over landlines and then transmit normally on their own allotted channel numbers.

More elaborate aerials at distances less removed from the station are required towards the fringe of low-power, booster and translator stations. Usually, however, such stations are designed for very local working, meaning that up to five or so miles from them a simple dipole or "H" (or "X") at the most is all that is required for good reception.

CHOICE OF BAND III TV AERIAL

The greater part of Great Britain is also extensively covered by a network of high, medium and low power Band III stations. Band III is used mainly by ITV and in certain areas of the BBC for 405-line transmissions. Because of the higher signal frequency, somewhat more elaborate aerials (though not necessarily larger overall) than used in Band I are required for comparable Band III reception.

The single dipole is suitable for use only very close to the station, in a very high signal field, and then it is often folded. Next, there is the three-element array ("H" and "X" aerials are rarely seen on Band III) and this is suitable for reception up to about 10/15 miles from a powerful station, depending on the local screening and topography. Five-, six- and eight-element arrays (comprising the dipole and a reflector and directors) are needed for reception up to 30 miles from a station. Beyond that distance ten-, eleven-, twelve- or even more element arrays are needed to secure that little extra signal that is so important to the signal/noise performance of a set working under fringe-area conditions.

There is not a great deal to be gained from employing in-line Yagi arrays with more than about eleven or twelve elements. We saw in Chapter 3 that a law of diminishing returns takes effect beyond a certain number of directors, and it is neither physically nor economically desirable to go on adding elements in line. More gain and improved directivity can be obtained, however, by arranging two complete Yagi arrays in parallel, broadside or stacked.

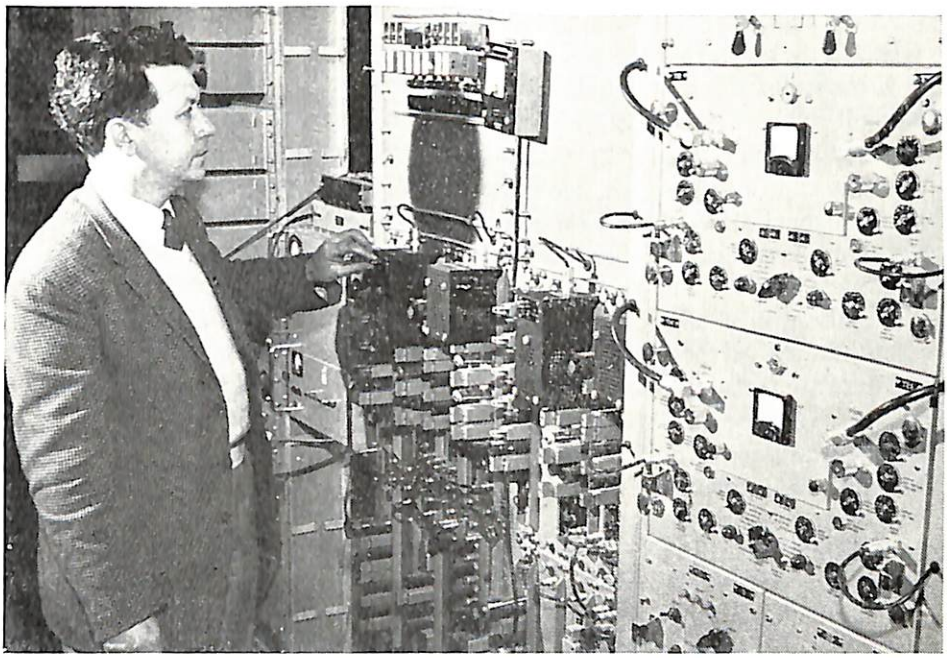


FIG. 4.2. *Inside a BBC television booster or "translator" station. (Photo: Oxford Mail and Times Ltd.)*

Band III aerials for use towards the fringe or in poor reception areas of bad topography and screening are thus of this variety. Most are of broadside configuration, embodying from about five to about eleven elements in each array, thus providing from about ten to 22 elements in total. These arrays are designed specifically for broadside mounting, but it is possible to parallel in a similar manner a pair of ordinary multi-element Yagi aerials, provided due attention is given to their spacing and matching to the feeder (see Chapter 3).

CHOICE OF U.H.F. AERIAL

There are many more problems in covering the whole of a country with a consistently high signal field in Bands IV and V, for the reasons expounded in Chapter 1. *This means that the type of aerial system needed for good u.h.f. reception may differ widely even over relatively small distances.*

Moreover, the length of the elements of these aerials is short compared with those of lower frequency aerials. This results, from the dipole's aspect, in a lower signal voltage being delivered to the feeder. A single dipole on Band V, for instance, would deliver about 100 μV of signal due to a signal field of the order of 1 mV/metre, while a single dipole on Band III in a signal field of the same intensity would deliver a signal approaching 500 μV. On

Band I the signal delivered would be about 2,000 μV (i.e., 2 mV). Here, then, is revealed the effect that the dipole length has on signal pickup.

It is not possible to make the dipole any larger than the tuned length, and making it full-wave does nothing to improve the pickup substantially, as we have already seen (Chapter 2). Folding does not help, either, as this mostly affects the centre impedance. However, since the length of the elements is short (not much more than 5 in. at the high-frequency end of the Band V), many more of them can be used without introducing serious mechanical and mounting problems. The spacing between the elements is that much less as well, resulting in an elaborate, but compact design of probably no greater weight than the partnering Band I, Band II or Band III aerial.

There are further factors with regard to the u.h.f. signal field, dealt with in Chapter 1. There it is shown that the radiated signal field rises with decrease in signal wavelength even when the transmitter power is unaltered. The *effective radiated power* (e.r.p.) of a transmitter is greater on the u.h.f. bands because the smaller elements and components of the transmitting aerials permit the use of arrays of *greater gain* than is possible on the lower frequency bands. E.r.p.'s up to 500 kW and 1 MW are used in the u.h.f. bands. (Remember this is not the power of the transmitter by itself, but the power of the transmitter multiplied by the gain of the transmitting aerial. The e.r.p. may be at maximum in one direction only.)

The smallest u.h.f. aerial is the three-element. This comprises a matched dipole, a reflector system that may consist of a wire mesh arrangement, a single element or several elements, and a director. Whatever type of reflector system is used, it is classed as just a single element. This kind of array would be suitable very close to the station in a good reception area.

For use within a radius of about 15 miles from a powerful station a five-element array may well be needed. Bad reception spots, even within this radius, demand something even better, and in-line Yagi aerials with up to 22 elements are available.

Outside the service area and for some bad spots within the service area broadside and stacked arrays offer advantages. It is impossible to generalize in this respect, and systems with two arrays side-by-side (broadside) and with two stacked (one above the other) broadside arrays are available for very poor service area locations and for more distant reception over reasonable signal paths. These range from a total of 20 elements up to 72 elements! Sometimes there are more for special conditions. A 72-element system would comprise four 18-element in-line Yagi arrays arranged in stacked-broadside formation. This is almost the ultimate that is feasible under ordinary domestic conditions.

If two Yagi arrays are made into a stacked or broadside system the overall power gain is twice that of just one of the Yagi aerials. The addition of a further *pair* of arrays steps up the power gain again by a factor of two or 3 dB.

Other advantages of this technique are the small angle of acceptance (i.e., narrower beam width) and an improvement in bandwidth over that which would be given by an in-line array using the same number of elements.

ATTIC AND ROOF-SPACE AERIALS

The greater the signal frequency, the greater is the signal attenuated in passing through walls and the roofs of houses. We have already seen (Chapter 1) that m.f. and h.f. signals are very little affected by passing through walls, trees and even hills. Low v.h.f. signals are a little affected in passing through objects like walls and roofs, but even so quite good pickup is possible under average conditions by the use of a Band I aerial in the roof-space or attic. The biggest problems are in orientating the aerial for the best signal pickup in the limited space and in keeping the aerial clear of pipes, cables and water tanks which can very seriously affect its characteristics, as we have already seen.

Sometimes there is insufficient height in the roof-space or attic to allow a vertical aerial to be properly erected. Compressed aerials are available for these conditions and some are made with angled elements, thereby reducing the overall height without affecting the tuning. Where the signal is vertically polarized a horizontal slot aerial can be used in spaces of very limited height. This type of aerial is described in Chapter 3.

Attic or roof-space Band I aerials are often suitable for distances up to 20/25 miles from the station, and for greater distances at high receiving sites. The author obtains very good reception on Channel 2 with a two-element J-Beam attic aerial over a distance of about 30 miles from the station and at an altitude of 160 ft above sea level.

At locations of poor signal/interference ratio a roof-space or attic type aerial is not desirable, and this generally applies to main road locations. Provided the interference field is relatively small, the use of a transistor booster with a simple attic type aerial can often give good results, even at distances up to 40 or so miles from the station. Signal boosters are dealt with in Chapter 6.

Roof-space and attic aerials become less effective at Band III frequencies, but it is, nevertheless, still possible to obtain reasonable reception if the aerial can be kept well clear of metal objects (including the outside metal guttering) and orientated for the best pickup. Interference problems are less on Band III, of course. Again, a low-noise transistor booster can help with an attic Band III aerial system, probably more so than at Band I because of the relatively improved noise performance of transistors at the higher Band III frequencies.

If the nature of the reception area is such that normally six-element chimney-mounted Band III aerials are needed, then comparable reception is

often possible by the use of a nine-element attic aerial. The extra gain of two or three additional elements often counters the loss of bringing the aerial into the roof-space and of the reduced height. It is far better, of course, to use indoor aerials if at all possible. They are not exposed to the weather and need not be so mechanically robust as their outdoor counterparts. They are a step in the right direction towards clearing the skyline of the unsightly display of metal rods which usually marks the television era!

Band II aerials are somewhat less of a problem to use in the attic or roof-space. They are horizontally mounted and generally smaller than their Band I partners. Also, we have seen that impulsive and electrical interference of all kinds has little effect on sets responsive only to f.m. signals. Attic or roof-space f.m. aerials can generally be employed up to 30/35 miles from a powerful station. Towards the fringe of this distance "H", "X" or three-element arrays may be needed, but up to about 15/20 miles a single horizontal dipole is often adequate. At distances in excess of about 35 miles a signal booster can be used in conjunction with an attic aerial (two- or three-element) provided the location is not too troubled with interference. At distances up to 50 miles from a powerful station it is best to take the aerial outside, unless the signal field happens to be fairly high due to the altitude of the receiving site.

Low-power and translator stations generally put sufficient signal field into the towns or areas they are designed to serve to allow the use of attic aerials, though there are invariably pockets of low signal field round the area, due to heavy screening etc. (depending on frequency), where lofty outside aerials are needed to secure the full advantage of the local transmitter.

Whether or not u.h.f. aerials will be of much use in the attic or roof-space depends upon many more factors than were enumerated for the v.h.f. bands. U.h.f. signals suffer considerable attenuation in making their way through a wall and roof, especially if their surfaces happen to be wet or damp. Dry slates or tiles probably offer the smallest attenuation in this respect, and reasonable results are possible when an attic aerial is looking straight into the roof at distances up to ten miles or so from a powerful station, though this is dependent on the local signal field.

On the other hand, such an aerial may be useless if the direction of the station demands that it be orientated so that its forward direction is along a line of houses. The signals are then greatly attenuated before arriving at the aerial due to their passage through many walls and roofs. The solution here is to mount the aerial on the chimney stack or side wall, if possible, so that it has an unobstructed "view" in the line of the station. These aspects are shown in Fig. 4.3.

Clearly, it is impossible to give hard and fast rules concerning the use of roof-space and attic aerials, particularly in the u.h.f. bands, for here the signal strength can differ considerably from house to house, so that while

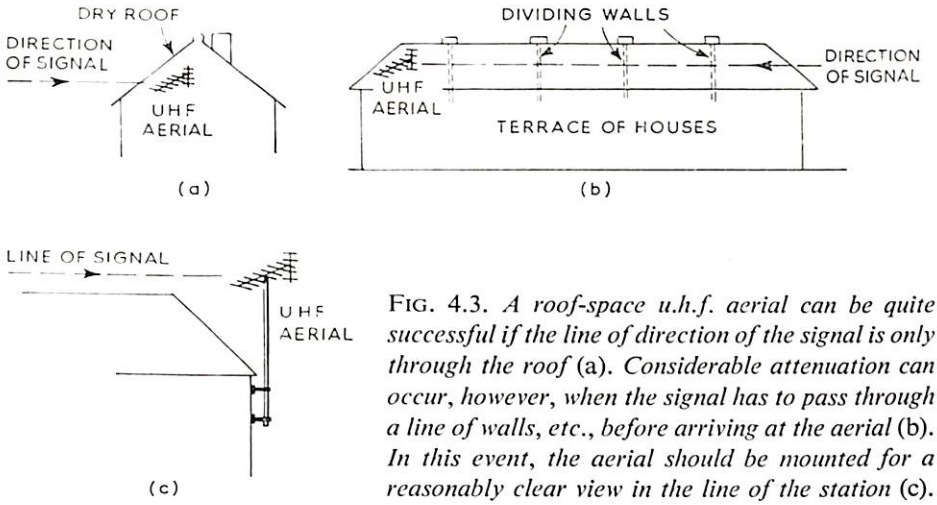


FIG. 4.3. *A roof-space u.h.f. aerial can be quite successful if the line of direction of the signal is only through the roof* (a). *Considerable attenuation can occur, however, when the signal has to pass through a line of walls, etc., before arriving at the aerial* (b). *In this event, the aerial should be mounted for a reasonably clear view in the line of the station* (c).

one viewer may get reasonable reception with an attic array his immediate neighbour may get nothing with a like array similarly placed in his attic! There is a lot of variation between the sensitivities of sets on the u.h.f. channels, incidentally, so poor results in one house and good results in another could mean that the sensitivity of one set is above that of the other, the less sensitive set requiring a stronger aerial signal than the other to produce a comparable picture. Recent dual-standard and 625-line-only monochrome and colour television sets feature transistorized tuners, and these can work from a smaller signal than the valve tuners.

In the v.h.f. bands one can usually secure reasonable reception from roof-space or attic aerials if the outdoor aerials in the immediate area are no more complex than a single dipole on Bands I and II (or up to an "H" or "X") with a three-element array on Band III. In the v.h.f. bands it is usually best to use an extra two elements if the Band III aerial is brought into the roof and one extra element on the Band I and II aerials to counter the losses. It must be remembered, however, that quite a lot of signal can be lost due to the close proximity of the aerial to a metal water tank or a run of pipes or cables, resulting in both screening and mismatching.

On the u.h.f. channels the largest possible roof-space type of aerial should be utilized, even where it appears that a less complex aerial may suffice, as in very wet weather and at certain times of the year the signal in the roof-space may fall in strength. In any case, too much signal is far better than too little.

ROOM AERIALS

It would seem that the ideal solution to the aerial problem would be the use of small, decorative type of set-top or set-side aerials. Unfortunately,

this kind of aerial can only be used in areas of extremely high signal field and low interference. They are much more susceptible to the pickup of random interference since their lack of altitude means that they are placed where the intensity of domestic electrical interference is at its highest. (This also applies to car ignition interference, for this is radiated at a fairly low angle to the earth.)

Thus, room aerials of all descriptions are not at all satisfactory where interference fields of any intensity exist. Small levels of interference, however, can be tolerated where the wanted signal field is high, for then a reasonable signal/interference ratio can be maintained.

Room and set-top aerials take many forms, as we saw in Chapter 3. On Band I rods made to form a "V" shape comprise the dipole, the rods being adjustable in length to tune approximately to the required channel. There is a certain degree of directivity with this sort of aerial, maximum pickup being along the length of the "V". These rods are also arranged to pick up the Band III signals, provided they are strong enough. In this case, the lengths of the rods are adjusted as a compromise for the best reception of signals in both bands. Sometimes it is necessary to adjust the length of the rods and orientate the aerial each time the channel is changed. These aerials can also be used for the reception of f.m. signals in Band II.

Set-top aerials have been known to work up to 20 or so miles from a powerful station under favourable reception conditions (i.e., high site and low interference). Aerials with amplifiers can work over greater distances, as shown in Fig. 3.34.

Room u.h.f. aerials can more closely resemble a properly tuned aerial than their lower frequency counterparts, due to the relatively smaller size of the elements. These, however, can generally be employed only very close to a station or at a site of very high signal field. They are very much affected by the proximity of objects and bodies in the room, the signal often fading with movement of a person or object! Nevertheless, there are locations where they can give quite good results, and because of their greater gain than v.h.f. room aerials they can often be orientated very accurately, thereby strengthening the signal by several decibels.

An interesting example of this sort of aerial is the "Discus", which is illustrated in Fig. 4.4. This is a three-element Yagi array, flattened out! It is rather as though a steam-roller had been allowed to pass over an ordinary three-element array. The resulting wafer aerial is mounted between p.v.c. discs, the aerial then being like the filling of a sandwich, the "bread" being black, circular p.v.c. laminae. This design is possible, of course, because the u.h.f. signals—in the areas where this kind of aerial can be used—are horizontally polarized.

Some aerials for room use are all-channel designs, as shown in Chapter 3,

FIG. 4.4. *A u.h.f. set-top aerial by Belling & Lee Ltd. This utilizes a flattened Yagi three-element design built into a disc sandwich.*

but these are suitable only in those areas where the signal field from all stations is exceptionally high. Of course, it is permissible to use a room or set-top aerial for the strongest station, with an attic aerial, say, for the station which is not quite as strong and an outside array for the weakest station.

ALL-BAND AERIALS

This brings us to the choice of all-band aerials generally. This sort of aerial is usually designed to have maximum gain on the u.h.f. section and lowest gain on the Band I section, the idea being to obtain almost equal signals from a group of co-sited stations. Unfortunately, this ideal state of affairs rarely exists, and in some cases where the stations are not co-sited one or more section needs to be independently orientatable. Provided the signal unbalance over the channels is not excessive the automatic-gain controls of the set will adjust the gain according to the signal strength, the differences not then being troublesome.

However, if the signal on one channel is very weak, excessive picture grain and sound hiss will be present when that channel is received. In this event, a separate aerial for that channel may be necessary. When this happens an all-band aerial may not be the true answer to the problem.

There is also the possibility that one of the channels may yield a very strong signal, causing overloading at the set. Normally, when this is the case all channels have to be attenuated to reduce the signal on the one offending channel. This is all right provided the remaining channels can stand having their signals reduced. If not, reception on the remaining channels will suffer as the result of reducing the overloading on one channel, which is not very logical.

While all-band aerials are ideal for minimizing the number of separate aerial units per dwelling, they are thus only successful when the signals in the area are fairly well balanced. This does not mean that all the signals should be of exactly the same strength, for the sensitivity of many sets is far greater on Band I, for instance, than on Bands IV and V. Actually, the

sensitivity usually falls progressively from the low-frequency end of Band I to the high-frequency end of Band V, meaning that signals of increasing strength are required for comparable reception (referring to signal/noise ratio) from Band I to Band V.

Now, to provide equal aerial signals, the field strength in an area has to rise quite steeply from the low-frequency to the high-frequency bands, as shown in Table 4.1. From this it can be seen that for approximately equal set signal/noise ratios, a signal field of rising intensity from Band I to Band V is demanded. This is modified, of course, due to the inherent noise performance of different sets over the bands and by the complexity of the aerials selected for the individual bands. Rarely, as would be expected, does this signal field gradient exist in any area served by co-sited stations. This is what makes it necessary to use such a diversity of different aerial gains over the bands, with the u.h.f. aerial generally possessing the maximum gain. In areas where the stations are not specifically co-sited, all-band aerials can pose even greater problems, and under such conditions individual aerials are usually desirable.

CHOICE OF FEEDER

The type of feeder connecting the aerials to the set is important. Coaxial cable inputs are featured on all television sets used in Great Britain, though in other countries the design is often for twin-feeder.

Dual-standard television sets have two aerial inputs, one for the v.h.f. channels and the other for the u.h.f. channels. We have already seen that the attenuation given to a signal travelling in a feeder increases with increase in frequency. This means, then, that the feeder used on the u.h.f. aerial should be of lower loss than that used on the v.h.f. aerials. The lower the loss of the feeder, the larger its diameter. Special low-loss feeders are available for u.h.f. applications, and these can also be used to advantage on weak Band III channels. Medium-loss cable is generally suitable for Band I channels, where the feeder loss generally is the lowest.

However, it may often pay to use low-loss cable for all bands when the

Table 4.1

APPROXIMATE FIELD STRENGTHS FOR TELEVISION BANDS

Band	*Local Field Strength* ($\mu V/m$)
I	150
III	450
IV	1,500
V	3,000

extent of the feeder run is greater than normal. Runs in excess of about 50 ft should be of low-loss cable unless the signal strength at the aerial happens to be almost twice the required value for good signal/noise performance. There is little point in going to great lengths to abstract the maximum possible signal from the radio waves if almost half of it is to be dissipated in feeder losses!

Sometimes the feeder will be called upon to carry the signals in two or all of the bands. When the u.h.f. signals are commonly carried in this way the use of low-loss feeder is essential for best results. Chapter 5 deals with signal combining to a common feeder and with the splitting of the signal bands at the set end.

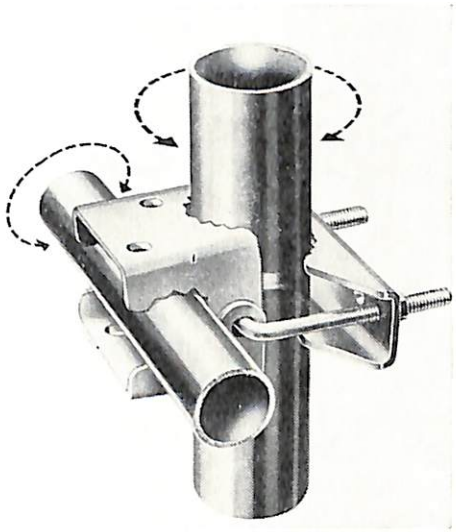


FIG. 4.5. *Details of a universal bracket. (Antiference Ltd.)*

BRACKETS AND CLAMPS

Aerial makers supply a host of brackets of various kinds for the safe erection of their aerials. Each maker has his own pet ideas and some of these are in the form of patented brackets, clamps and so forth. It is impossible to detail here all the various types of fixing arrangements; these are available from aerial catalogues and leaflets. Some of the methods employed will be looked at, however.

Fig. 4.5 shows a "universal clamp" and Fig. 4.6 a further selection of brackets etc. from the Antiference range. The universal clamp can be used for fixing an aerial cross-boom to the mast or for fitting an aerial of different channel or band to a common mast. It can accommodate up to 2 in. diameter masts and permits orientation in the two modes shown by the dotted arrow lines.

Referring to Fig. 4.6, at (1) is shown a surface bracket that can be secured by screws to any flat surface and allows a 180 deg. swing of the aerial mast. This can take up to 1 in. diameter masts. (2) shows a typical wall-mounting bracket for masts of 1 in. to $1\frac{1}{4}$ in. diameter, while (3) is a simple single chimney lashing for lightweight aerial systems using masts of 1 in. diameter. For the chimney-stack mounting of slightly heavier and larger aerial systems there is the double-clamp arrangement shown at (4).This

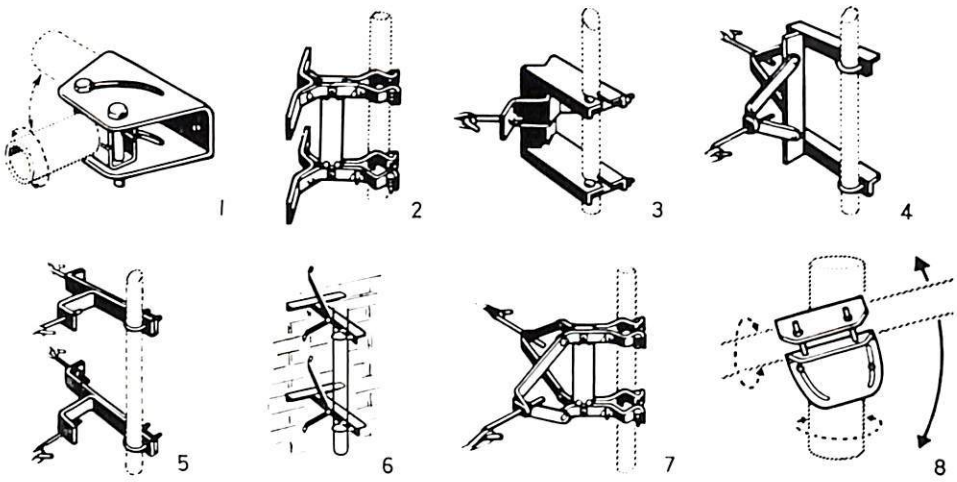


FIG. 4.6. *Selection of brackets.* (*Antiference Ltd.*)

takes masts up to $1\frac{1}{2}$ in. diameter. At (5) a much more sturdy chimney-stack lashing is shown. This uses two separate lashings and brackets and can accommodate masts up to 2 n. diameter. A double wall-mounting arrangement for up to 2 in. diameter asts is shown at (6), while at (7) is a single-stack lashing for masts up to $1\frac{1}{4}$ in. diameter.

At (8) is shown a three-way clamp for fixing an aerial cross-boom ($\frac{3}{4}$ in. to 1 in.) to a mast of up to 2 in. diameter. There is also a tilting clamp for square booms and a three-way clamp for square booms. The action of this is shown by the arrows in the illustration.

A selection of wall brackets from the J-Beam range is shown in Fig. 4.7. At (*a*) is a very simple arrangement for lightweight aerials, at (*b*) a more substantial arrangement, and at (*c*) something substantial for supporting

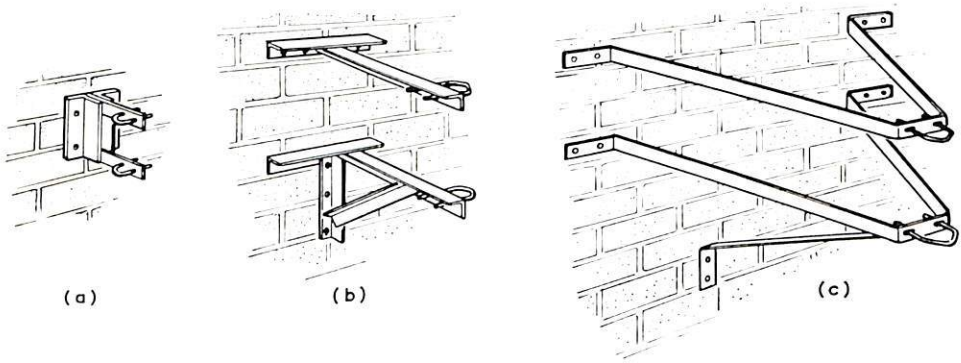


FIG. 4.7. *Selection of wall brackets.* (*J-Beam Aerials Ltd.*)

really heavy multiple systems.

Two wall-type brackets from the Fringevision range are shown in Fig. 4.8. That at (*a*) is made of cast alloy and is suitable for any facia mounting of light weight, while that at (*b*) is suitable for heavier systems.

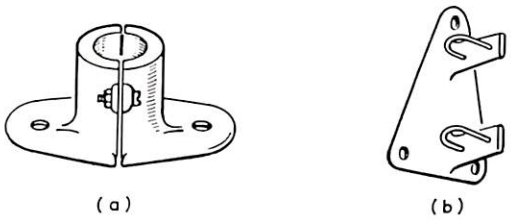


FIG. 4.8. *Wall brackets.* (*Fringevision Ltd.*)

AERIAL MASTS

The early idea was to use wooden poles for mounting aerials, for it was considered that metal would adversely affect the aerial performance. While this was probably true so far as early aerials were concerned, the modern aerial mast is invariably made of a lightweight metal alloy, the aerials having been designed electrically to partner a metal mast without ill effect. Masts of 2 in. diameter support the heavy arrays, and staying is not usually required for ordinary heights (up to about 10 ft or so). Single lightweight aerials, however, are supported by shorter masts from $\frac{3}{4}$ in. to about $1\frac{1}{2}$ in. diameter, depending on length, weight of aerial and requirements.

The lightweight type of mast is made in various shapes and sizes to assist the aerial erector with most of his problems, though sometimes he may find it necessary to have a special mast or bracket made for an abnormal requirement. A selection of masts in current use is shown in Fig. 4.9. Used in conjunction with the brackets previously mentioned, almost any type of aerial mounting configuration is possible, as will be appreciated.

Brackets, clamps, booms and so on for creating broadside and stacked arrays are also made, as also are various offset mountings for u.h.f. aerials. Various arrangements of this nature are shown in Fig. 4.10, with a selection of horizontal broadside systems and offset mountings.

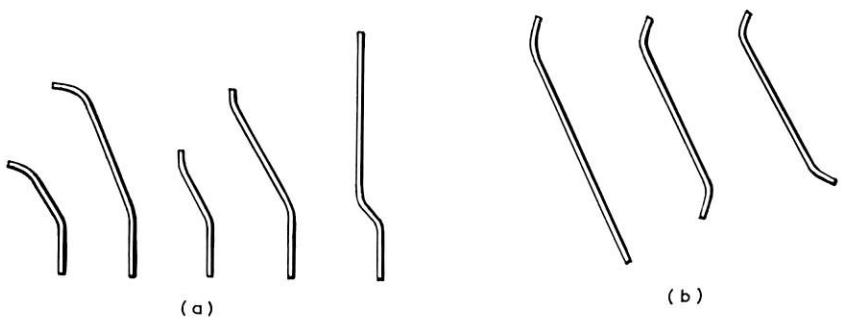


FIG. 4.9. *Selection of lightweight masts by Antiference* (a) *and J-Beam Aerials* (b).

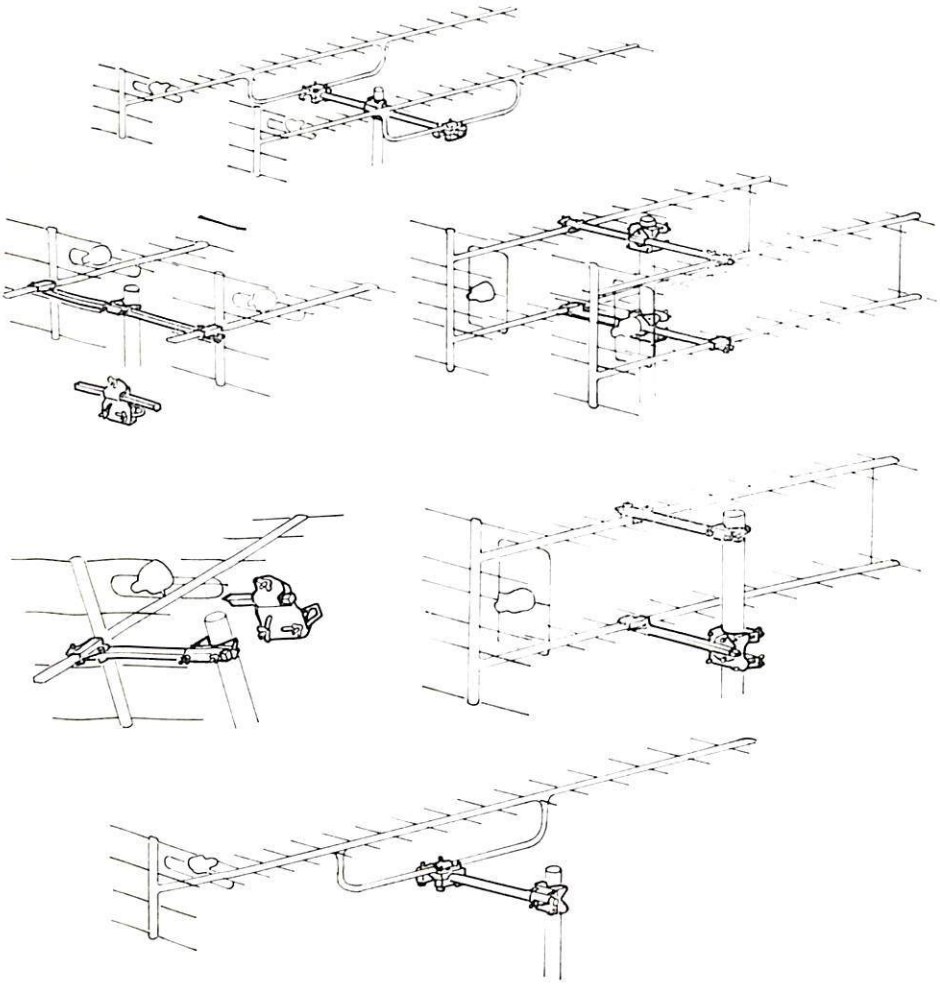


FIG. 4.10. *Showing arrangements for broadsiding arrays and standing-off arrays from the mast.* (*J-Beam Aerials Ltd.*)

Other items of aerial hardware include extension sleeves for coupling two standard-size masts for increased aerial height, hook guy clamps for aerial mast staying, cranked arm fixing brackets, universal brackets of all weights and sizes etc. There is something to suit nearly every type of aerial-mounting problem that could ever arise.

LOADING FIGURE

Aerials, masts and associated fittings are designed with a large safety margin, ensuring many years of life which can be extended further in some

instances if the metalwork is painted on erection and regularly thereafter during normal property maintenance. In their literature Messrs. Belling & Lee Ltd. state that "associated with every Belling & Lee outdoor aerial there is a 'loading figure' which represents the strain imposed by the aerial on its mounting in peak gusts of wind. Masts, brackets and lashings are classified in three groups (light, medium and heavy duty) for each of which a *Load Acceptance* figure is given. It is essential to see that the loading of an aerial does not exceed the load acceptance of the mounting with which it is used.

"This system of matching the array to its mounting through a load figure is a simple and realistic way of ensuring that every installation will be safe under normal wind conditions at any time of the year. Where more than one array is to be erected on a common mounting, the loading of each aerial should be added together to determine the class of mast, etc., necessary.

"When a u.h.f. aerial on its own light-duty mast is to be mounted on a v.h.f. installation, it is advisable not to put the u.h.f. aerial higher than the top of the main mast without checking very carefully that the lashings, etc., will withstand the additional bending strain. Provided the u.h.f. aerial is not higher than the top of the main mast, the simple load matching procedure applies, but the loading of the extra mast must also be taken into account."

Some manufacturers provide "add-on" units which will convert a basic u.h.f. aerial to an array of greater number of elements and hence gain. One system permits four basic units to furnish a complete range of u.h.f. aerials, thereby easing the dealers' stocking problems. A simple extension fitted to the 5- or 6-element array converts it to a 10-element array, and this is possible without the use of tools. Simple accessory kits enable 10-element aerials to be assembled in broadside or as a stacked-broadside array. Not all makers, however, adopt this philosophy.

It is the usual practice to assemble the aerial system on the ground and then carefully take it up to its mounting points. Extreme care should be taken over the erection, and the assembly instructions supplied with the aerial should be strictly observed. Bolts, nuts and wing nuts should not be over-tightened but they should be sufficiently tight to prevent their becoming loose due to wind vibration. *Always use the anti-vibration washers supplied.*

SYMPTOM OF LOOSE ELEMENTS

Elements becoming loose are costly to cure, as it means taking the aerial down again from the mounting, which can be a two-man ladder job. Poor electrical connection between the centre of the dipole or the parasitic elements and the cross-boom will not cause the reception to cut on and off, but often produces a disconcerting growling noise on the sound and intermittent dark, horizontal bands on the picture, as the wind alters the contact resistance.

Folded dipoles are in direct electrical connection with the cross-boom at

the centre of the continuous folded section. This is possible, of course, because the centre of a complete half-wave dipole is at zero signal potential, and so can be "earthed". The same reasoning applies to the tuned parasitic elements—the physical centre of these is also at zero signal potential. In effect, then, the dipole and all the parasitic elements of an array with a folded dipole are in direct electrical connection with the cross-boom and, usually, the cross-boom with the metal mast.

Ideally, the whole of the aerial should be connected to an efficient earth point through fairly heavy gauge copper wire. With the type of aerial mentioned this can be accomplished easily enough by bonding the earth wire to the metal mast, either via a special earthing clamp or by a terminal. An earthed aerial system affords a reasonable degree of protection against static build-up, since it acts to some extent like a "lightning conductor".

Even without a separate earth connection, however, there is generally a fairly low resistance path between the aerial and earth, via its mounting. The coaxial cable braid at the set end may be earthed, and this connection automatically earths the aerial, via the braid's connection at the folded dipole.

A straight dipole is not in d.c. connection with the cross-boom, of course, since the insulator at the centre isolates both halves of the dipole from the boom. Nevertheless, a good earth connection to the common metal parts, mast, cross-boom and parasitic elements is still desirable.

CONNECTING THE FEEDER

Care should also be taken over connecting the feeder to the dipole terminals. The braid of the coaxial downlead is best connected to the bottom half of a vertical dipole, with the inner conductor to the top half. This is not essential, but is often considered the best plan.

Where a balun is used, it does not matter which way round the dipole is connected. Aerials with baluns and matching sections should be treated with special care, for quite a lot of signal can be lost by mis-connections here. U.h.f. aerials are particularly prone to incorrect or bad connection at the dipole, and the coaxial should follow the route from the array as arranged by the maker.

AERIAL SPACING

The distance between separate aerial arrays should be spaced from each other by at least one wavelength, taking the wavelength of the lowest band or channel aerial as the measure. This is necessary to keep interaction between the adjacent aerials as small as possible.

The most popular aerial mount is the chimney stack. Here the aerial mounting bracket (or brackets) is secured to the corner of the stack by a tensioned lashing wire; two separate wires being employed with a two-

bracket mounting. It is usual to pass the wire or wires round the stack and back to the other side of the lashing bracket. The lashing wire is made-off at both ends with special thimbles, and tension is applied to the wire by screwing a nut on the end of "J" bolts threaded through corner holes in the lashing brackets.

This method of aerial fixing is very well known and needs no special attention. The idea is simply to keep the lashing bracket tight into a corner of the stack by the tensioned wire. Once tensioned, it is surprising how much weight the bracket will stand by this method of fixing. To prevent the lashing wire from cutting into the other three corners of the stack, corner plates are used, specially designed to hold the lashing wire to their centre without slipping off.

Contrary to belief, a solid double chimney lashing does much to strengthen a weakened chimney stack. It draws in the bricks and thus makes a collapsing stack somewhat safer. Nevertheless, a stack which is obviously in a bad state of decay should only be used to support an aerial with extreme caution, for while the lashing may hold the stack up, the levered weight of the aerial in a strong wind could pull the bricks apart and cause the stack to fall down.

Apart from "J" bolts, there are other patented arrangements for tensioning the lashing wire round the stack. A simple lightweight aerial requires only a single lashing and 1 in. mast of short length, while more elaborate arrays and multiple systems demand a 2 in. main mast and a heavyweight, double lashing system.

HUMMING MAST

Masts are generally tubular, to keep the weight low. The open end of a mast can cause the tube to act somewhat like an organ pipe in the presence of wind, and when mounted on a chimney stack a very disturbing low-frequency hum is transmitted down the chimney into the house. Really bad air resonance effects of this kind appear to set the whole house in a state of very-low-frequency vibration during rough weather, and if the aerial is mounted on a common chimney stack, the next-door neighbour gets the same effect, and is usually not very happy about it once he has discovered its origin, which may take some time!

Specially designed chimney-mounting masts avoid this trouble, and non-treated masts can be cleared of the trouble by blocking both ends with wooden bungs. The vibration effect in wind is also minimized by the use of heavy rubber grommets on the mast clamps of the corner lashing bracket. The mast is then clamped within the grommets instead of being metal against metal.

Some chimney stacks are too large for successful lashing or are of ornate shape, making life difficult for the aerial erector. In these cases the mast

brackets are fixed to the corner of the stack by screwing into the brickwork with some patented fixing arrangement, such as the metal expansion type of Rawlplug. These are very effective for this type of work and hold really solid, but for the best results a special hard "Rawlplug drill" bit and electric drill are needed. This means running electric power up to the stack, demanding extreme caution, and precautions against electric shock. The metal body of the drill *must* be properly earthed on the green wire in the proper electrical manner.

Wall-mounting brackets also call for drilling the wall and Rawlplug fixing. Solid coach bolts of the "self-threading" variety are ideal for this; they need to be tightened with a spanner. Alternatively, the Rawlplug type of expansion plug with a threaded end can be employed, and nuts used to clamp the brackets against the wall. Care should be taken when drilling the wall or brickwork to ensure that the holes line up accurately with those drilled on the fixing surface of the brackets. Wall damage should be treated by a builder.

Attic and roof-space aerials are usually easily fixed as they are designed with facia lightweight brackets. Alternatively, the aerials can be hung on the cross-beams of the roof-space by cord, after ensuring their correct orientation. As already mentioned, these aerials must be kept clear of roof-space metalwork.

It is often necessary to take the kit of aerial parts into the attic or roof-space and assemble it there owing to lack of size of the trap door to pass the aerial in fully assembled. Some sort of illumination is required for this operation. An extension light from the landing bulb-holder provides bright electric light, which is far better than fiddling about in the light of a dim torch! Take care not to damage or dirty the ceiling round the trap door when entering the roof-space, and use a small ladder or substantial steps rather than a couple of chairs balanced one upon the other. The author has had considerable experience of the latter when handling complex arrays in his own roof-space.

The downlead can often be passed out of the roof-space beneath the eaves and then arranged to traverse the wall of the house to the window of the viewing room.

GROUND-FOUNDATION AND STAYED MASTS

The best plan when a stayed mast is demanded is to secure a properly designed kit of parts. It is, of course, possible to stay almost any type of mast and guy clamps can be purchased complete with fixing bolts that will suit masts from about $1\frac{1}{2}$ in. to 2 in. diameter. It is usual, however, to mount domestic television aerial systems on the wall or chimney stack of the building, as we have already seen.

Nevertheless, there may be conditions making it necessary to employ a

ground-foundation stayed mast. For example, certain local councils at one time prohibited the use of building-mounted aerials (that is, on council-owned dwellings). It was then necessary to erect stayed masts in the gardens. Each back garden thus displayed such a system. There was much non-skilled activity and it was not pleasant to look at rows of back-garden aerial masts from the end of the street, many at different angles from the vertical and all differently arranged.

A well-erected stayed mast capable of carrying three or four aerial arrays is costly—far more so than when the building is somehow used to support a shorter mast. To reduce cost, do-it-yourself aerial and mast fixings are sometimes used. These can be not only unsightly but also potentially dangerous. It certainly pays in more ways than one to employ the correct fixing components and to do the job properly or employ skilled operators to undertake the work.

A ground-foundation mast may also be required if the house is screened from the signal by a steeply rising hill. The aerial system may then have to be mast-mounted on the top of the hill, the signal being fed down to the house through low-loss feeder, probably via an amplifier to counter the cable losses.

FIG. 4.11. *A self-supporting mast ready for erection on its prepared concrete base.*

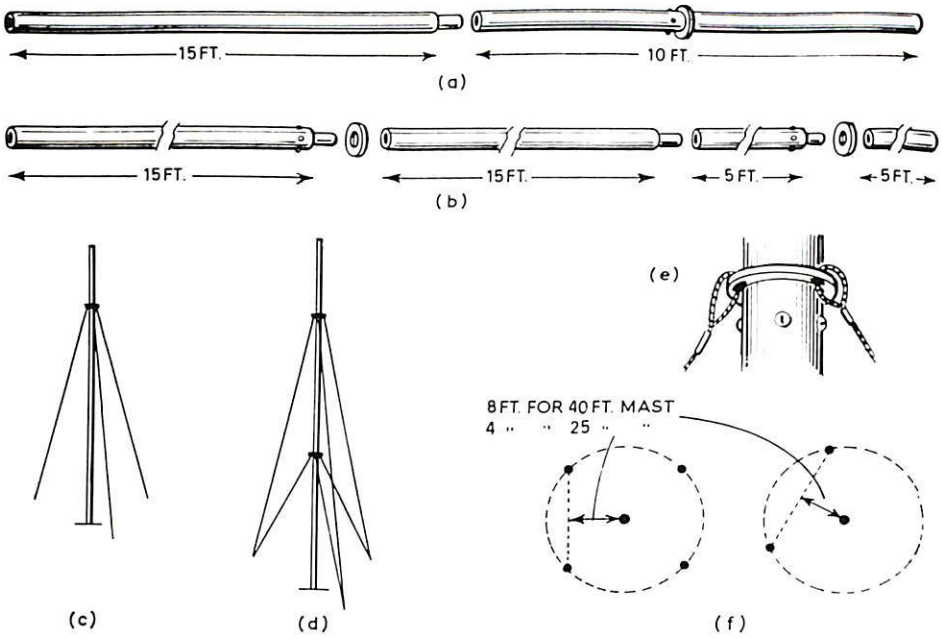


FIG. 4.12. *Details of a stayed aerial mast.* (*R.T. Masts Ltd.*)

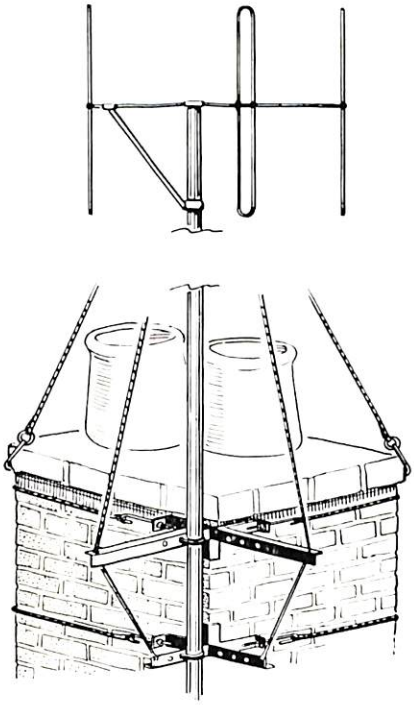
Prevailing high winds on the hill top make it even more important to make a sturdy job of the aerial system. If the expense can be tolerated, a good self-supporting mast is desirable. This is fixed to a concrete foundation in the ground in which is embedded the mast securing plate. The mast is then simply bolted on to this plate.

A mast of this nature is shown in Fig. 4.11. The fixing plates can be seen in the prepared concrete foundation, and these line-up with the partnering plates at the bottom of the mast. Masts of various heights using this design are available. Their cost can often be shared by a number of viewers misfortunately placed signal-wise at the foot of a hill, since the mast can accommodate a master aerial system that, via amplifiers, can supply the screened viewers with good-quality signals which they would not otherwise obtain. This technique is considered in greater detail in Chapter 5.

Details showing the construction and erection of two sizes of stayed tubular mast are shown in Fig. 4.12. At (*a*) and (*b*) are shown the component parts of 25 ft and 40 ft masts respectively, while how they appear when raised is illustrated at (*c*) and (*d*). Shown at (*e*) is the method of supporting the guy ring on the bolt heads fixed to the appropriate section, thereby allowing the mast to be rotated. At (*f*) is shown the method employed to ascertain the correct distance of the guys from the mast.

Erection involves laying the mast sections on the ground and then fitting them together as shown at (*a*) and (*b*). The joined mast is raised in a similar manner to the raising of a ladder. One person should anchor the bottom, another pull on the guy and a third walk the mast up. A clothes prop is handy when the mast reaches an angle of about 45 deg. for assisting final erection.

When masts in excess of about 15 ft are erected on a chimney stack it is often desirable to stay them, especially in locations of strong winds. A cleverly designed kit by the same firm facilitates the erection of such an aerial system, allowing the use of a 25 ft mast on the chimney stack, as shown in Fig. 4.13. A set of stout metal cruciform angles form outriggers to provide a suitable span between the guys or stays. These are fixed to the chimney stack by galvanized steel lashing wires, using "J" bolts in a similar manner to the lashings normally employed for chimney-stack mast mounting (Fig. 4.14).



(Left) FIG. 4.13. *Details of a chimney-stack-mounted stayed television mast by Sky-Mast. This can accommodate a 25 ft mast safely.*

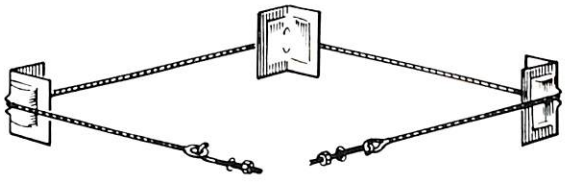


FIG. 4.14. *A chimney lashing.* (*Belling & Lee Ltd.*)

ERECTING AERIALS

Ordinary chimney-stack and wall aerials usually call for the assistance of two people to erect. As already intimated, it is first necessary to prepare the mast mounting brackets and to secure these on the chimney stack or wall.

For chimney work, two ladders are essential, one up to the guttering and the other on the roof. For the latter a special roof ladder is desirable, as slates or tiles can be broken or dislodged by hauling heavy wooden or metal ladders over the roof. On no account should one be tempted to walk direct on the slates or tiles. The ladders should be secured by rope to a tight and

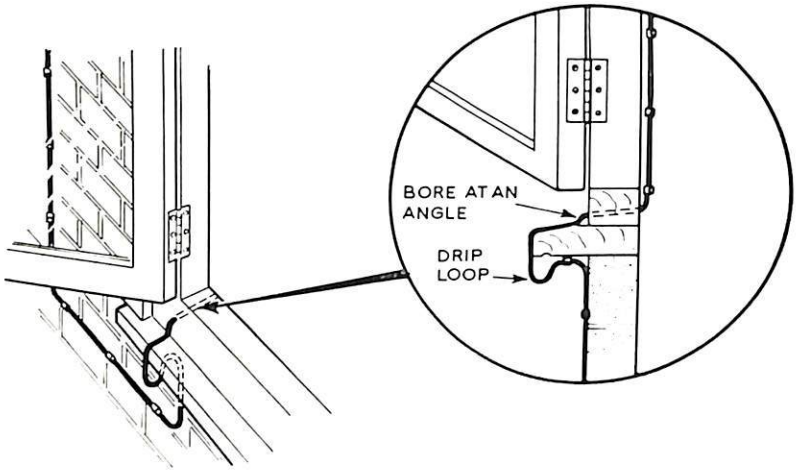


FIG. 4.15. *A drip loop formed at the point where the feeder enters the window avoids water entering through the hole. Note also that the bore through the frame is angled.*

solid guttering bracket. One operator can then take his place by the chimney stack and the other can handle the assembled aerial, eventually passing it to the man by the chimney. One should then support the mast in the brackets while the other attends to the clamps and bolts, but these are not fully tightened until after the aerial has been accurately orientated.

Adding U.h.f. Aerials. The trend is now towards adding u.h.f. aerials to existing v.h.f. aerial systems. In many cases the existing mast can be used, as we have already considered in some detail. Masts up to about 12 ft in length and 2 in. diameter secured by a heavyweight double lashing can generally cater for an extra u.h.f. array provided this is not placed as dead weight at the top of the mast. Theoretically, of course, the u.h.f. aerial should be the loftiest of the group, but for mechanical reasons this is not always possible.

If the reception conditions are such that a complex array is needed, then height will also be of utmost importance. In this event, it will almost certainly pay to use a completely separate u.h.f. installation. This will make it far easier to orientate the array for optimum signal pickup, for certain orientation compromises have to be adopted when more than one array is mounted on a common mast. This does not matter so much in areas of high signal field, but where the signal is weak and interference effects are troublesome, it is difficult to be certain that each array is operating as efficiently as it could on its own mast.

It must also be remembered—and this is very important—that a little wobble of the u.h.f. aerial is likely to have far more serious consequences in terms of picture flutter and so forth than a similar wobble on the less

critical v.h.f. aerials. This is because of the greater directivity of the u.h.f. aerial and the fact that these aerials are more sensitive to proximity effects, particularly when these are varying, like the aerial moving relative to a more stable aerial nearby.

Nevertheless, where conditions permit, the u.h.f. aerial can well be fixed to an offset mast or arm from the main mast, as close as possible to the stack, but not closer than one wavelength of the u.h.f. channel (that is, a little more than twice the length of the u.h.f. dipole). If u.h.f. reception is poor under this condition, the aerial should be fixed higher up the mast, *but only if the mast and associated fixing is solid enough to handle it.* If in doubt, always fit a new, larger diameter mast and brackets, etc.

It is worth remembering that the strength of a tubular mast is not necessarily indicated by its wall thickness or outside diameter. The strength of the alloy is also important. As an illustration, a 10 ft long, $1\frac{1}{2}$ in. diameter mast of 0·048 in. type NS4 aluminium-magnesium alloy has approximately the same strength as a similarly dimensioned mast made of 0·064 in. type NS3 alloy. NS3 alloy is less costly than the better class NS4 counterpart.

When the aerials are erected they will each have a downlead (except in the case of all-band arrays which have two downleads, one for u.h.f. and the other for all the v.h.f. channels which it serves and composite Band I, Band III aerials which have one downlead). These downleads will either be run separately or fed to a diplexer for connection to a common downlead, about which more is said in Chapter 5.

The downleads should be clipped neatly down the wall to the window of the viewing room, and a hole should be drilled in the outer frame to accommodate the feeder. To avoid water running down the feeder and

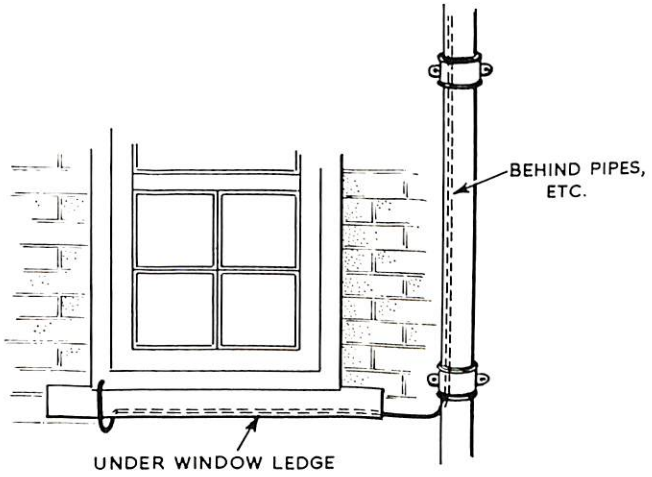


FIG. 4.16. *Showing how the downlead can be hidden on the face of a house.*

entering the window, a small drip-loop should be arranged as shown in Fig. 4.15. The water will then run off the bottom of this loop, bypassing the hole in the frame.

Fig. 4.16 shows how the downlead can be hidden behind the stackpipe and under the window ledge to avoid the unsightly display of wires over the front or rear of a house.

AERIAL ORIENTATION

Having erected the aerials, it is necessary to set them up to the signal so that they pick up as much of this as possible while providing the maximum discrimination against interference.

We have already seen that a simple dipole vertically-mounted is non-directional, so no matter how this is orientated there should be no signal increase. Nevertheless, variations in signal strength will be noticed at different dipole positions. This is caused mainly by the effect of objects, particularly large metal ones, close to the aerial. These will not only affect the dipole impedance but also absorb and reflect signal to some extent.

The best position for an outside aerial of this kind is either on the chimney stack or on a wall of the building facing the station, and this applies especially to Band III dipoles (see Fig. 4.17). The wall then to some extent acts as a large reflector. Mounted on the opposite wall, away from the station, the signal will be greatly attenuated by its passage through the building. When the wall is acting as a reflector it will also reduce the amount of interference picked up behind the dipole.

One of the biggest problems is in determining just how much signal the aerial is delivering at the end of the downlead and how this signal is varied when the orientation and position of the aerial is changed. If the picture on the set is viewed (or the sound listened to) an increase or decrease in signal strength may not be noticed owing to the action of the set's a.g.c. systems. Most television sets provide very good sound even from a very weak signal, while on the vision the brightness and general contrast of the picture remains fairly consistent over wide variations in signal level.

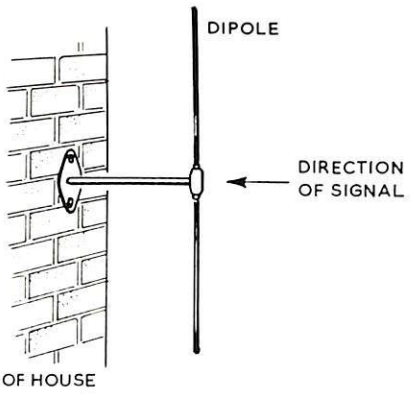


FIG. 4.17. *A single dipole is best mounted on the wall facing the station. The wall then to some extent acts as a reflector and also cuts down interference from the rear.*

However, on vision a weak

signal increases the background grain considerably (sometimes called "picture snow"), and one way of setting the aerial is for minimum picture grain, or "noise", as it is sometimes called. This is very difficult when the set is indoors and the aerial somewhere outside or on the chimney stack! It is, of course, possible to employ a person to report on the picture while the aerial is being set, but this is rarely successful owing to lack of good communication between the two operators. Moreover, it is often difficult to discern small changes in picture grain.

To assist with this method of aerial setting, telephonic communication between the man by the aerial and the set operator is desirable. A simple telephone can be thus rigged. A pair of high-impedance headphone earpieces connected in parallel either side of a suitable length of plastic-covered flex makes an adequate telephone for this application. Each phone piece is used as both transmitter and receiver.

At least one firm has developed a special two-way intercom system for aerial riggers. The mobile end is designed for attachment to the rigger's belt or it can be carried round the neck by a cord. Connection between the set-side unit and the mobile unit is by twin plastic flex.

Probably the best way of aerial setting is by the use of a signal strength meter or comparator. There is now available a wide range of such units which read signals from a few microvolts up to many millivolts over the television and f.m. bands. While there is a trend towards an "all-band" model, most models are for either the v.h.f. channels or the u.h.f. channels. Some are mains-operated, some battery-operated and others suitable for both mains and battery operation. All that is necessary is to plug the downlead into the aerial socket on the instrument and tune to the required channel. The feeder-end signal is then indicated directly on a calibrated scale, allowing the aerial to be positioned and orientated for the maximum signal pickup. Such instruments are also useful in locating sources of electrical and r.f. interference.

SET SIGNAL AND AERIAL GAIN

Just how much signal is required by a set for the best signal/noise ratio is difficult to ascertain, since much depends on the design of the set and on the noise figure of its tuners. Sets with transistor tuners will operate generally on a signal nearly half the strength of that required by valve tuners. As a rough guide, a modern set with a valve tuner can produce an acceptable Band I picture on 250 μV of signal. For a similar signal/noise ratio, Band III calls for some 400/500 μV, Band IV for 1,000/1,500 μV and Band V for 2,000/2,500 μV. Sets with transistor tuners can produce similar pictures with less signal. This is because transistors are somewhat less noisy in operation than valves at v.h.f. and u.h.f.

If a dipole only picks up half the required signal, then an aerial of greater gain must be employed. The gains of aerials are given relative to a single dipole, but while a dipole is inherently non-directional, a multi-element aerial is directional—which is why it has gain, as we have seen. The question of aerial gain is thus most important when considering the type of aerial necessary for a particular area of signal field (see Table 4.1, which gives the approximate field strength required for a received signal/noise ratio of not less then 25 dB in each television band). Aerial directivity is also used to combat interference, as we shall see.

One can glean a good idea of the type of aerial system required in an area by the aerials already in use, also from signal field contour maps such as those published by the BBC and ITA. Radio dealers usually plot their immediate trading area in terms of the aerials required for good reception, relative to the signal field; and, of course, from experience of working in the area over many years. The opening of a new channel or of a u.h.f. station, however, calls for a certain amount of experimentation before one can be

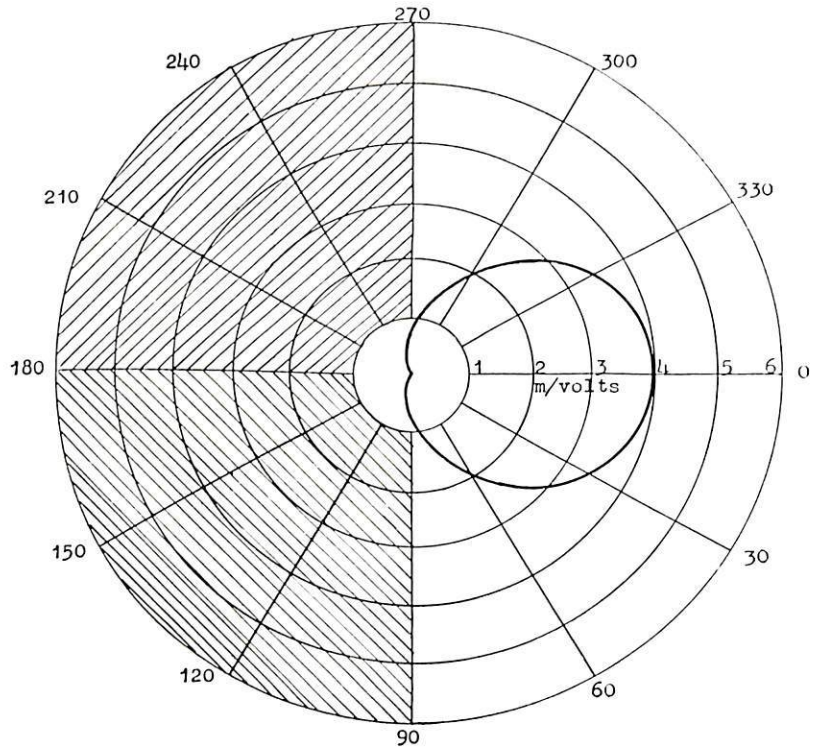


FIG. 4.18. *Polar diagram of three-element aerial. How this can be used for aerial orientation is described in the text.*

sure of the new aerial requirements. It is generally better to veer towards the use of aerials of more than the required gain, than less.

With u.h.f. in particular, the commencement of new stations in the local group could modify the requirements as determined for the first operating channel, even though the stations of a group will usually be co-sited.

As more and more u.h.f. stations come on the air, the likelihood of inter- and co-channel interference will increase, which is one reason why the Post Office and other authorities have recommended that *u.h.f. aerials with five or more elements have a minimum front-to-back ratio of* 16 *dB*. This means that stations at the rear of the aerial will normally give very little interference, even though they may be on the same (or adjacent) channel as the wanted signal arriving at the front of the aerial.

The relatively large number of elements on a u.h.f. aerial makes them more directional than their v.h.f. counterparts, which is why multipath interference on the u.h.f. bands is relatively small. Reflected signals from directions other than within the narrow angle of acceptance of the aerial are thus greatly attenuated.

This brings us to the question of orientating an aerial for the best signal/interference ratio. Fig. 4.1 shows that some interference discrimination is possible even with a horizontally-mounted dipole; but such discrimination due to a simple dipole is not very effective. If the direction of the interfering signals falls anywhere within the wide acceptance angle of this kind of aerial, then nothing much can be done to minimize it.

USE OF POLAR DIAGRAM

This is where the polar diagram of a directional aerial can be exploited to advantage. Fig 4.18 shows a polar diagram of a three-element Band I aerial. The actual "sensitivity" of the aerial at all directions round it is given in terms of millivolts, though it could equally be given in some other term, such as decibels. This diagram implies that the strength of the signal field arriving in the forward direction of the aerial (i.e., zero deg.) is such that a signal of 4 mV is delivered by the aerial. Now, if the aerial is turned 60 deg. either side of its forward direction (i.e., 300 deg. or 60 deg.) the signal delivered by the aerial drops to 2 mV. By this reasoning, it will be seen that the aerial signal is down to the region of 1 mV when the aerial is about 75 deg. off direction. At the rear of the aerial (i.e., 180 deg.) the aerial signal is zero. Clearly, then, maximum signal is delivered by the aerial when it is exactly on beam to the signal, as it were.

Now, let us suppose that we have an interfering signal of field equal to that of the wanted signal arriving, say, at 60 deg. and that the aerial is orientated for maximum pickup of the wanted signal. In spite of the equal strengths of the wanted and unwanted signals, the interference will produce

2 mV and the wanted signal 4 mV. We thus have a signal/interference ratio of 2-to-1 (or 6 dB). This, of course, is not very good, and the interference would badly affect the reception. Usually, however, the interfering signal would be greatly below the field of the wanted signal, and a far better signal/interference ratio would result.

Suppose the interference is arriving 90 deg. off the forward acceptance of the aerial, and that, again, the wanted and unwanted signal fields are equal. The aerial now would deliver only about 0·5 mV of interference and still 4 mV of wanted signal, giving a signal/interference ratio of 8-to-1 (or 18 dB), which is reasonable.

If we now turn the aerial 30 deg. off the beam of the wanted signal, the wanted signal would produce about 3·5 mV of signal, while the interfering signal would produce something less than 0·5 mV. In fact, the interference may drop to about 0·1 mV (i.e., 100 μV). In this case, while we have lost

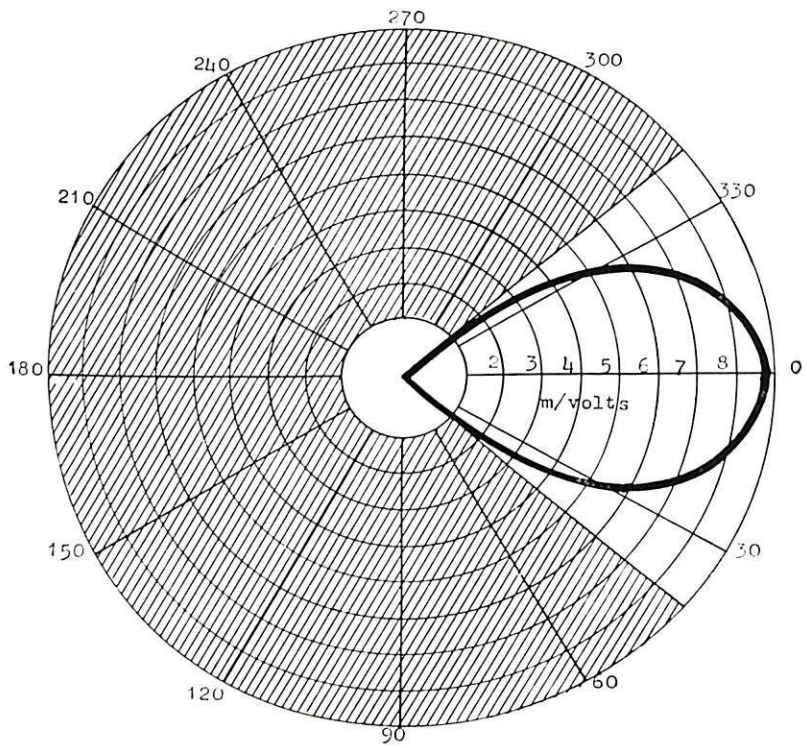
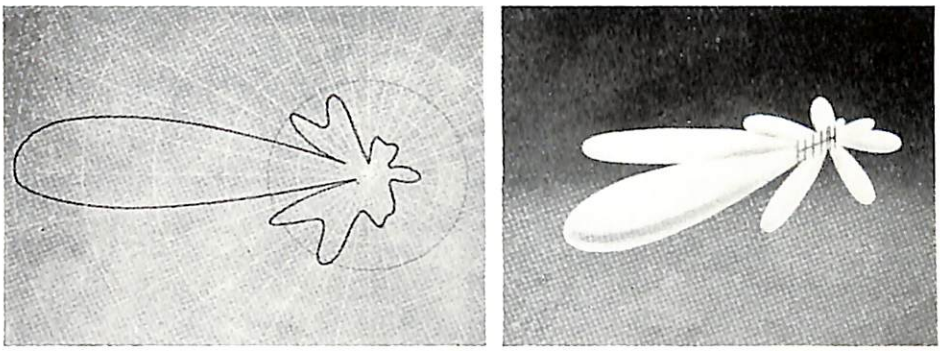


FIG. 4.19. *Polar diagram of more directional aerial than corresponding to the diagram in* FIG. 4.18. *In both diagrams, the unshaded areas approximate the acceptance angle of the aerials, while the shaded areas indicate the directions where the pickup of interference is greatly reduced.* (*J-Beam Aerials Ltd.*)



(a) (b)

FIG. 4.20. (a) *Polar diagram showing minor lobes at angles removed from the major lobe, which need to be taken into consideration when employing an aerial for maximum discrimination against interference.* (b) *Representation of the overall polar diagram of an aerial, which shows that aerials have a response to signals arriving off the horizontal.* (*Belling & Lee Ltd.*) *Reduced vertical response is possible by the use of stacked arrays, and such aerials are desirable for minimizing aircraft flutter effects.*

0·5 mV of wanted signal, we have increased the signal/interference ratio to about 35-to-1, about 31 dB, which is an improvement of about 13 dB. These examples clearly reveal how careful orientation of the aerial can improve the signal/interference ratio, and show why it may not always be desirable to turn the aerial for maximum pickup of the wanted signal.

Greater discrimination against interference is possible, by the use of an even more directional aerial. Fig. 4.19, for instance, shows the polar diagram of such an aerial by J-Beam. In both diagrams, the unshaded areas approximate the acceptance angle of the aerial, while the shaded areas indicate where the response is considerably curtailed.

Owing to the relatively large number of elements on a u.h.f. aerial, such arrays exhibit quite small acceptance angles and large angles over which the signal pickup is negligible. It is most important, therefore, that u.h.f. aerials be very accurately orientated to avoid large loss of wanted signal. If interference is arriving close to or towards the edge of the acceptance angle, only a small angle of misalignment will be necessary to optimize the signal/interference ratio. If the misalignment is excessive, the desirable forward gain characteristic of the aerial will be lost.

However, it must also be remembered that complex arrays may have several small lobes or acceptance areas removed by quite large angles from the main lobe or acceptance area. A polar diagram of such an aerial (by Belling & Lee) is shown in Fig. 4.20 (*a*). While this aerial may be orientated for the best signal/interference ratio relative to the main or major lobe, interference

arriving at angles corresponding to the minor lobes could well cause trouble. The response at the minor lobes is, of course, generally below that at the major lobe, but strong interfering signals could get in.

There are other aspects of this matter, one being that the polar diagram applies generally to signals at one particular frequency, and that at signals of different frequency—though probably within the passband of the television system—the polar diagram may differ a little on both the major and minor lobes. Good aerial design, however, minimizes this possibility considerably within the bandwidth concerned.

Another aspect is that the polar diagram for a vertical aerial is plotted for signals arriving in a horizontal plane. This means that the response of the aerial to signals arriving from directions other than the horizontal is not usually revealed. Fig 4.20 (*b*) gives a better idea of the overall response of an aerial (one with major and minor lobes) by Belling & Lee. This reveals that the aerial would have some response to signals arriving at angles above and below the horizontal.

Then there is the aspect of the response of a vertical aerial to horizontally polarized signals. All these aspects are important when considering the type of aerial best suited for interference suppression.

It should be remembered that car ignition interference usually arrives below the horizontal, while signals reflected from aircraft arrive above the horizontal. Desirably, therefore, aerials for the maximum suppression of traffic and aircraft interference should have reduced angles of acceptance from above and below.

So far as traffic interference is concerned, this affects mainly the Band I television channels, its intensity falling swiftly towards the high-frequency end of Band III, while Bands IV and V are almost completely free from such disturbance. The chief trouble nowadays (also bearing in mind that most motor vehicles are reasonably well suppressed) is interference from passing aircraft (see Chapter 1). Stacked arrays offer a weakening of the vertical response of an aerial, and in areas where aircraft are troublesome this type of array is well worth trying, both on f.m. radio and on television. Indeed, stacking can assist with the attenuation of any signals arriving at angles from the horizontal.

AERIAL TROUBLES

One of the quickest ways of checking an aerial is to connect its downlead to a signal strength meter, so as to measure the voltage of the signal that it is actually delivering to the set. Apparent lack of sensitivity of the set could be caused by a faulty aerial system delivering a low signal to the set. If a signal strength meter is not available, a set-top aerial or even lengths of flex cut to suit the local channel and connected to coaxial cable at the

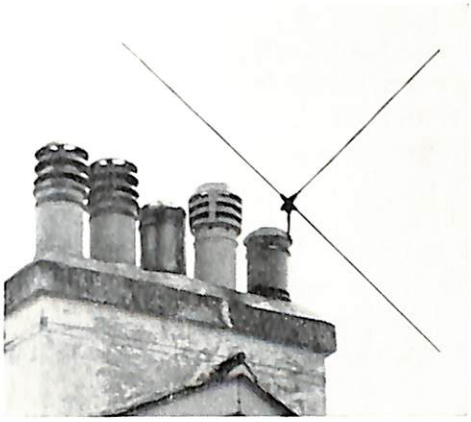
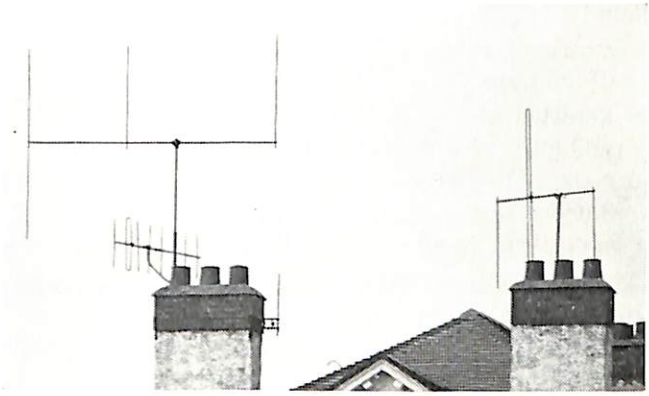


FIG. 4.21. *The missing element from this "X" aerial affects the aerial's ability to discriminate against interference. In this case, the gain is also reduced.*

FIG. 4.22. *These aerials have two half-elements missing. They are thus virtually useless for operating in the fringe area for which they were chosen.*



centre could be used as a test in a location of high signal field. Of course, such simple types of aerial would probably not give reception equal to that from the correctly working aerial—now suspect—but they may give a clue as to the condition of the permanent aerial. If reception from the improvised test aerial is equal to or better than that from the permanent, suspect aerial, then there would almost certainly be something wrong with the aerial system.

If all the channels carried by the common downlead are weak, the fault is more likely to lie somewhere in the feeder/diplexer (or triplexer) system rather than in the aerials. The connections to the coaxial plugs, sockets and filters (i.e., diplexer or triplexer) should be investigated firstly at the set end of the cable. If all is well here it may be necessary to check on the cable connections at the dipole, and this usually means taking the aerial down. After periods of high winds, poor reception troubles abound, especially at exposed locations.

Wind can cause an aerial not properly secure in its mounting to turn like a weathercock, and if the aerial is reasonably directional, quite a

reduction of signal will result, particularly in areas of low signal field. Thus, if reception on one channel—usually one in Band III, IV or V—is weak after a storm, the orientation of the aerial should be checked.

A check should also be made for missing elements! It is not uncommon to discover after a windy night aerials looking something like those pictured in Figs. 4.21, 4.22, 4.23 and 4.24. The effect of just a half parasitic element missing may not be unduly detrimental to the reception, unless the location is in the deep fringe, but if the aerial was originally orientated and chosen for discrimination against interference, conditions such as those shown in Figs. 4.21 and 4.23 would undoubtedly cause a fall in signal/interference ratio. A missing half dipole would be a different matter; here the signal would be considerably weakened.

Two elements missing, such as from those aerials in Fig. 4.22, would considerably affect the directional characteristics and almost certainly cause a rise in co-channel interference troubles, a fall in signal/interference ratio generally and a weakening of the signal, demanding a greater contrast setting on the receiver. The mess depicted in Fig. 4.24 would be responsible for a very bad picture, for here only half the dipole (slot in this case) is connected to the feeder. This is about the only element contributing to the collection of signal, and this rocks and waves in the wind!

Apart from elements leaving the aerial, they tend to become loose after years of windy exposure. The symptoms arising from this trouble have already been described—namely rumbling on sound and intermittent dark, horizontal bands on the picture, in accompaniment with the movement of the elements in the wind.

When elements fall off the centre impedance of the dipole is affected in addition to its signal pickup qualities. The transference of signal from the dipole to the set's aerial terminal then varies. This happens intermittently due to loose elements, being one reason for the type of symptoms given above.

AERIAL INTERACTION

The impedance of a dipole is also affected by the nearness of other aerials. A set-up such as shown in Fig. 4.25 is highly inefficient due to the interaction of the different aerials. Indeed, some of the aerials are so close together that their elements touch during windy weather. The solution is to space the aerials out on two chimney stacks (if available) or to leave the Band III arrays (and possibly the u.h.f. aerials) on the chimney stack and bring the Band I and Band II aerials into the attic or fix them on a wall of the house.

The aerials shown in the picture are obviously old ones and close to deterioration. Another solution would be to replace them with a modern combined array, assuming that the signal field is sufficiently high and the

FIG. 4.23. *The missing half of the director on this array impairs mostly the polar diagram and the interference discrimination properties. The gain is little affected.*

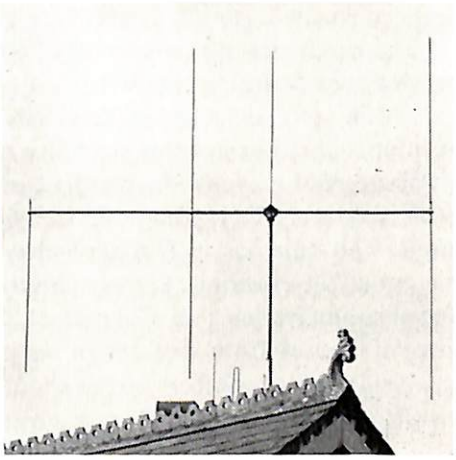


FIG. 4.24. *This aerial is probably almost useless, its only active element being half the slot dipole dangling on the feeder.*

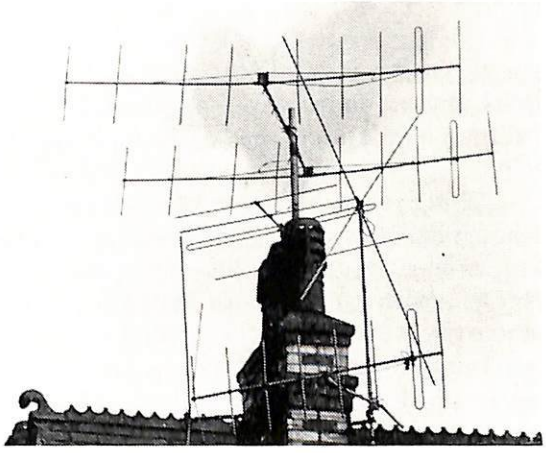


FIG. 4.25. *The close grouping of aerials as in this instance reduces the potential performance of each aerial. This applies especially to u.h.f. aerials.*

stations co-sited. No u.h.f. aerials are shown here, but these could be mounted on a separate mast on the chimney above the v.h.f. aerials, assuming edge-of-service-area or fringe conditions.

Many semi-detached houses have a single, shared chimney stack and it is impossible to expect this structure to accommodate all the aerials for two dwellings that may now be required in a fringe area. There would be two for BBC1, two for ITV1, two for f.m. radio and two for u.h.f., making a total of eight. The time has in fact arrived when semi-detached neighbours should share one set of aerials. Signal splitters and two-way amplifiers are available for this application (see Chapter 5). Indeed, it is not difficult to service a row of houses from one set of aerials. This would solve the interaction problems, for, remember, aerials should be spaced by at least one wavelength of their own dimensions from each other to minimize interaction troubles.

Aerial riggers are currently running into trouble with interaction on the u.h.f. bands. Lack of chimney room means that these aerials have to be fixed very close to the existing aerials. This can affect the performance of both the new u.h.f. aerials and the v.h.f. aerials. This trouble also occurs when a semi-detached neighbour has a u.h.f. aerial chimney-stack-installed following the erection of the other neighbour's u.h.f. aerial. The latter may have obtained good u.h.f. reception at first, but which was greatly impaired by the subsequent erection of the partnering u.h.f. aerial. The only solution is to separate the aerials as much as possible by using a wall of the house, a stayed mast or even the roof-space for the v.h.f. aerials.

High-gain u.h.f. aerials are more sensitive to proximity effects than lower-gain v.h.f. counterparts. This means that the u.h.f. signal delivered to the set can fluctuate widely if the u.h.f. or partnering aerials wobble in the wind. It is essential, therefore, to ensure the optimum stability of mounting where u.h.f. aerials are concerned or associated with the overall installation.

TILTING AERIALS

Where it is impossible to avoid a close mass of aerial metalwork and one aerial appears to be adversely affected by the proximity of others, tilting the array a little above the horizontal in the forward direction can sometimes help.

Tilting can also be useful for fringe reception and in areas where signal bending has resulted in a slight change in plane of polarization of the signal. The aerial is best tilted a little upwards, preferably while observing a signal strength meter to ensure, in fact, that an increase in feeder signal results. Moreover, it can be useful in combating interfering signals arriving at the aerial at a low angle. For instance, if aircraft flutter is troublesome, the aerial can be tilted down a little, while if traffic interference is the main trouble it can be tilted up a little.

Tilting an aerial solely as a means of increasing the effective height may not always be desirable, since this can cause a greater than normal response to reflected signals and thus aggravate multipath interference effects which can be rather disturbing with colour television.

It has already been mentioned that the plane of polarization of v.h.f. and u.h.f. signals can change due to propagation over relatively long-distance paths. In this respect, there have been reports giving the impression that the polarization might change by different amounts over the sound and vision signals of a television channel. This is not to say that the polarization affects the frequency of the signals, but that the *polarization change* differs in amount, a little at different frequencies.

The implication here is that while a u.h.f. aerial may be tilted, say, to line up with the effective plane of polarization of the vision signal over a long-distance path, this may not correspond to the exact plane of polarization of the sound signal. The vision signal would then be greater at the end of the feeder than the sound signal. Conversely, the tilting could be adjusted to favour the sound signal, when the vision signal would be the weaker of the two. These conditions may not be consistent but may alter with changes in atmospheric conditions. Of course, one would not expect this to happen within the service area of a u.h.f. station, but it is as well to have the possibility in mind. The solution where the effect definitely exists is to tilt the array for the best compromise between sound and vision.

We have seen, then, that a mismatch can arise due to a break or short in the cable system and due to a change in impedance at the dipole. These things are reflected back to the set end of the cable, and under bad conditions of mismatch an appreciable change in picture strength and quality results when the cable at the back of the set is moved around. This is a clear indication of incorrect matching.

On most aerial systems a feeder break can be ascertained simply by connecting an ohmmeter across the inner and outer conductor at the set end of the cable. A short-circuit (or very low resistance) should be recorded due to the continuity between the terminals of a folded dipole. Note, however, that the effect may be modified by the presence of a diplexer or triplexer in the coaxial circuit.

An open-circuit in the feeder system is difficult to prove conclusively, since there may be capacitor isolation in a filter or aerial socket; or perhaps none of the aerials concerned has a folded dipole, in which case an open-circuit would be recorded whether the feeder possessed continuity or not along its length.

At one time it was considered a good idea to fit a fairly high value resistor across the terminals of a straight dipole, actually at the aerial insulator. A value of 1,000 ohms or so would not affect the performance

of the aerial, but it does permit the feeder to be checked for continuity simply by applying an ohmmeter across the set end, the meter reading the same value as the resistor at the aerial if the feeder is intact. Modern folded dipoles and combining filters offer difficulties with this idea, though it may apply still in certain cases.

Out-of-phase waves going back up the feeder from a mismatch at the set's aerial socket can cause an impairment in definition of the picture. Absolute "ghosting" symptoms rarely occur, however, since the signal delay in the cable is insufficiently long. "Ghost" effects can occur on very long cable systems due to matching troubles.

After years of exposure to all weathers the metal parts of an aerial tend to corrode. So far as mounting arrangements and masts are concerned, regular painting should hold back this trouble for many years. It is not possible to paint the aerial at its electrical connections, of course, since this would impair electrical conductivity and greatly reduce the efficiency of the aerial.

There comes a time, then, when an aerial must be replaced, and with the continuously changing television conditions it may be found that the replacement aerial can be much smaller than the original, while in many cases a combined array will be suitable, owing to a booster or more local station being brought on the air since the original aerial system was erected. Indeed, by replacing old aerials with more efficient modern types the present singularly untidy skyline should progressively undergo a change for the better. There will always be fringe areas, particularly so far as u.h.f. is concerned, but the extensive long-distance reception of the early days will no longer apply. Each area will be served by its own set of f.m. radio and television stations on all bands.

Town stations of relatively low power, transmitting items of local interest along with popular music, are already operational in areas of high population. These transmissions are in Band II and can thus be picked up by the ordinary Band II regional-tuned aerial.

It should be added that the chimney stacks of modern houses having few fireplaces are not strong enough for a multiplicity of aerials to be attached to them safely. Dangerous stresses can be caused by fixing large arrays to one-flue chimneys.

CHAPTER 5

Signal Combining and Splitting

SOMETIMES it is required to combine to a common feeder the signals in different bands or channels picked up by two or more independent aerial systems. In this case it is desirable to employ a filter network that not only matches the signal sources to the common feeder but also isolates the signals in the aerials from each other.

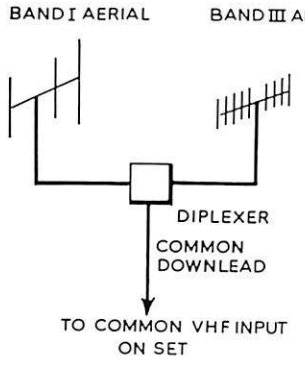
Television sets have only a single aerial socket for all the signals in the v.h.f. bands, including the f.m. sound signals in Band II where the set has facilities for the reception of f.m. radio programmes. Thus, if each aerial has its own downlead the correct downlead has to be plugged into the set every time a new channel is selected. This is extremely inconvenient and unnecessary. A simple selector switch could be used to switch to the set the required aerial system, but again this is unnecessary as it is possible to use matching and isolating filters instead.

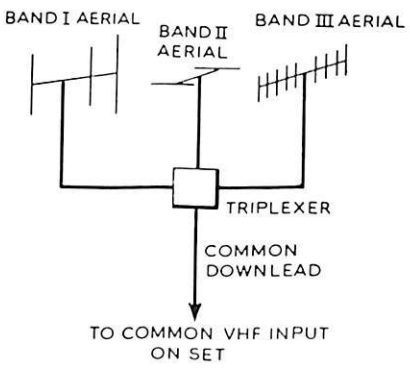
The simplest filter of this kind has three terminals, one for connecting to the downlead of the Band I aerial, another for connecting to the downlead of the Band III aerial and the third for connecting to the common downlead to the set, as shown in Fig. 5.1.

DIPLEXERS AND TRIPLEXERS

Since this filter handles two signals it is called a "diplexer". It permits free passage of the Band I signals picked up by the Band I aerial to the common downlead, while attenuating any Band III signals that may be picked up by that aerial. Conversely it permits free passage of the Band III signals picked up by the Band III aerial to the common downlead, while attenuating any Band I signal that may be picked up by that aerial. Moreover, it serves to match the Band I and Band III aerial and common downlead terminations, thereby avoiding loss of signal and reflections in the downlead.

If just an ordinary resistive matching pad were used, with no signal isolation features, any Band I signals picked up by the Band III aerial would be fed to the set while tuned to the Band I channel, and any Band III signals picked up by the Band I aerial would be fed to the set while tuned to the Band III channel.





(Left) FIG. 5.1. *A "diplexer" is used to direct the signals in a Band I and a Band III aerial to a common downlead with the least loss and interaction.* (Right) FIG. 5.2. *A "triplexer" is needed when the signals from a Band II f.m. aerial also require to be connected to the common downlead carrying the v.h.f. television signals.*

Thus, any spurious signals, such as co-channel interference, multipath interference and electrical interference in general, in one band picked up by the aerial tuned to the other band would detract from the signal supplied by the proper aerial. There would not be any point in this case in spending a lot of money on an aerial to get rid of interference and improve the picture quality if it were going to be impaired by spurious, interfering and cancelling signals injected by the aerial not at that time in use! It is most important, therefore, to ensure that aerial isolating filters do their job properly, especially in areas where expensive aerials are necessary.

Where it is necessary to add Band II signal to the common downlead, the aerial filter must have an extra section to feed the f.m. signal to the downlead without interaction between the Band I and III aerials and to maintain the correct overall matching. Since a filter of this kind handles three signals it is called a "triplexer", and it is connected as shown in Fig. 5.2.

The diplexer or triplexer can be positioned either near to the aerials, on the aerial mast, or at the set end of the downlead, depending on requirements. If mast-mounted only a single run of common downlead is necessary from the aerials to the set and this saves money. Nevertheless, where the ordinary downlead is likely to add considerably to the loss of a Band III signal, it may be best to run a separate Band III downlead of ultra-low loss and then combine the signals at the set end of the two downleads, using just a short length of cable from the diplexer to the set's aerial socket. In the majority of cases, however, the filter would be mounted in a waterproof box on the aerial mast.

Diplexers and triplexers are available in two varieties, for indoor and outdoor use, and on no account should a unit designed for use indoors be

used outside in an exposed position, for the inevitable ingress of moisture would certainly result in excessive losses.

SEPARATE U.H.F. AERIAL INPUT

Dual-standard television receivers have an extra aerial input socket for the u.h.f. signals, and there has been no attempt at the time of writing to combine the v.h.f. and u.h.f. inputs, even so far as "integrated" and all-band tuners are concerned. This means, then, that a separate circuit is required from the u.h.f. aerial in all cases. This is not a bad thing for it ensures that the u.h.f. aerial is working with the minimum of losses as an independent system. We have already seen that the u.h.f. aerial is more exacting than those of the v.h.f. bands. Even composite v.h.f./u.h.f. aerials are designed so that the u.h.f. section is an entity on its own, with its own feeder.

To avoid the use of separate v.h.f. and u.h.f. downleads, however, u.h.f./v.h.f. aerial filters are available. Two filter units are required, a waterproof version at the aerials and one in a more attractive finish at the set end of the downlead, as shown in Fig. 5.3. Figs. 5.4 and 5.5 show aerial-end and set-end

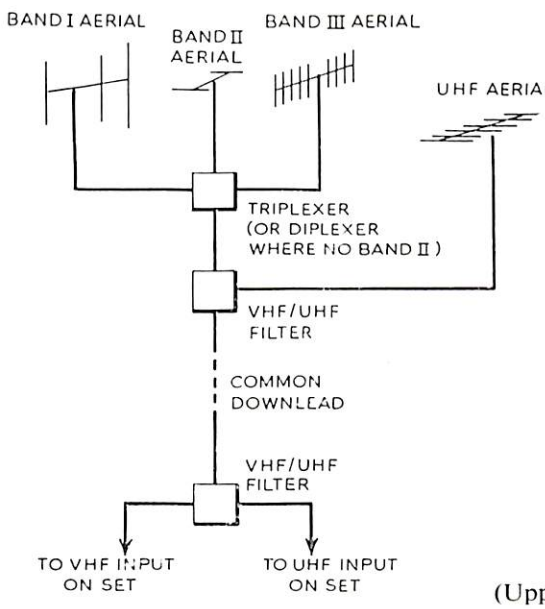
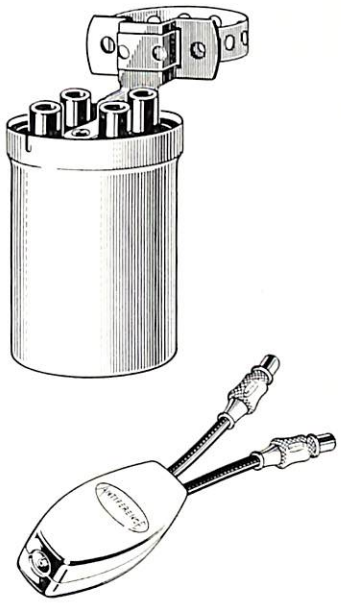


FIG. 5.3. *Where the common downlead is to cater also for the u.h.f. television signals, a pair of v.h.f./u.h.f. filters will be required at either end of the downlead.*



(Upper) FIG. 5.4. *Mast-mounted v.h.f./u.h.f. aerial filter.* (*Antiference Ltd.*) (Lower) FIG. 5.5. *Set-end v.h.f./u.h.f. filter which separates v.h.f. and u.h.f. signals for connection to the receiver's aerial input sockets.* (*Antiference Ltd.*)

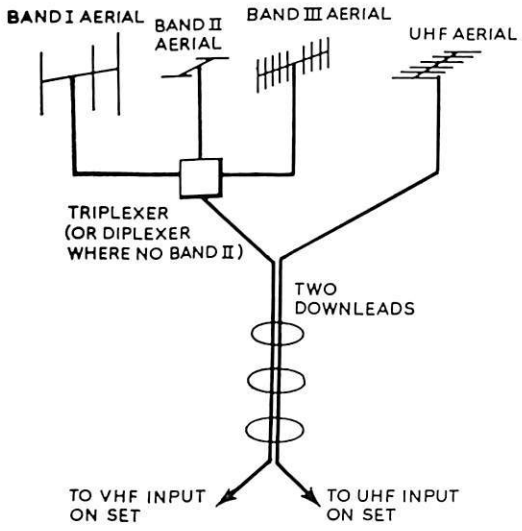


FIG. 5.6. *Separate v.h.f. and u.h.f. downleads are necessary in most installations to keep the u.h.f. signal losses as small as possible.*

filters of this type. The aerial-end unit features a clamp for securing to the aerial mast, this idea also being used for outside v.h.f. diplexers and triplexers. Waterproof grommets prevent water seeping into the unit.

The two filters, one at each end of the downlead, hold the v.h.f. and u.h.f. signals in electrical isolation, giving two isolated circuits, in spite of there being only a single downlead. This technique can only be adopted successfully in areas of high u.h.f. signal field, for signal losses are bound to occur at the filters and their terminations and these just cannot be tolerated in the u.h.f. bands and at locations of weak or mediocre signal strength.

In the majority of installations it pays to run two downleads, one for v.h.f. (the original one) and the other for u.h.f., because a downlead of less loss than that originally installed for v.h.f. is nearly always essential for the best u.h.f. performance. A two-downlead system is shown in Fig. 5.6, for comparison with that using a single downlead in Fig. 5.3.

Fig. 5.3 reveals that the isolated u.h.f. signal circuit is established after the v.h.f. triplexer (or diplexer). The filter at the top of the downlead provides an easy path for u.h.f. signal from the u.h.f. aerial to the common downlead and an easy path for v.h.f. signal from the v.h.f. aerials to the common downlead, but a high-loss path between the u.h.f. and v.h.f. aerial systems, thereby avoiding interaction between the v.h.f. and u.h.f. aerials.

The filter circuit at the set end of the downlead is similar to that at the top of the feeder, but is connected in reverse. Thus, only v.h.f. signals in the common downlead will get to the set's v.h.f. aerial input, with a high isolation factor to u.h.f. signals, while only u.h.f. signals will get to the set's u.h.f. aerial input, with a high isolation factor to v.h.f. signals. This explains why the single downlead effectively operates as two isolated signal circuits.

TWO BAND III INPUTS

In some areas two Band III programmes plus a Band I programme and the Band II f.m. sound programmes are available. We have seen that special

wideband Band III aerials are available to solve the Band III two-programme problem, the other bands then being added as already explained. However, there are instances where the signals of the two Band III channels arrive from different directions, meaning that a wideband Band III aerial is unsuitable (such an aerial being suitable, of course, only where the two Band III stations are co-sited).

A condition such as this demands the use of separate Band III aerials, and the problem then arises as to how two such aerials can be connected to a common downlead. The call here is for a special filter that electrically isolates the two Band III aerials, letting their signals pass independently into the common downlead. It is not possible simply to parallel two Band III aerials, hoping to get the best from both Band III channels, since the interaction and the mismatch effects would severely detract from the quality of both transmissions.

A "three-station diplexer" is available for one Band I channel and two Band III channels, and this would be connected in place of the ordinary diplexer in Fig. 5.1. Such a filter is not, at the time of writing, available for Band II in addition, but it would be possible to connect an extra filter to a triplexer circuit to cater for two Band III programmes, as shown in Fig. 5.7.

The Band III diplexer is of a type that has a low through loss independently from each Band III aerial to the outlet and a high isolation factor between the two aerials.

FILTER SECTIONS

We must now see what these aerial filters are made of. Actually, they are relatively simple and are made up of "filter blocks," each block designed to suit the circuit to which it is connected. Let us take the ordinary diplexer.

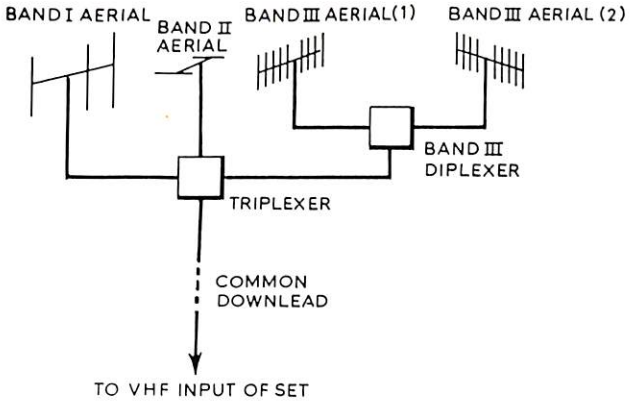


FIG. 5.7. *A special Band III diplexer is required to combine two Band III aerials to a common downlead system.*

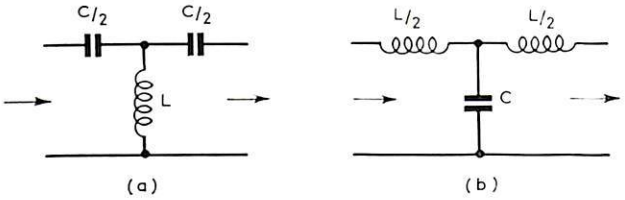


FIG. 5.8 (a) *Low-pass constant-k T-section filter and* (b) *high-pass constant-k T-section filter. Design formulae for* (a): $L = Ro/\pi fc$; $C = L/Ro^2$; $fc = 1/\pi\sqrt{LC}$ *and for* (b): $L = Ro/4\pi fc$; $C = L/Ro^2$; $fc = 1/4\pi\sqrt{LC}$, *where fc is the critical frequency, Ro the input and output impedance* (75 *ohms for television aerials and coaxial cable*), *L the inductance and C the capacitance.*

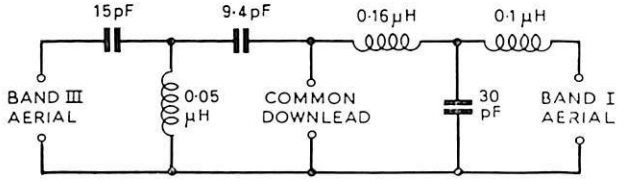


FIG. 5.9. *Combined high-pass/low-pass filter system forming a diplexer, with typical component values for Bands I and III.*

Here we have two filters, a high-pass filter from the Band III aerial to the common downlead termination and a low-pass filter from the Band I aerial to the common downlead termination. The high-pass filter passes only those signals above a critical frequency (such as those above Band I) while the low-pass filter passes only those signals below a critical frequency (such as those below Band III).

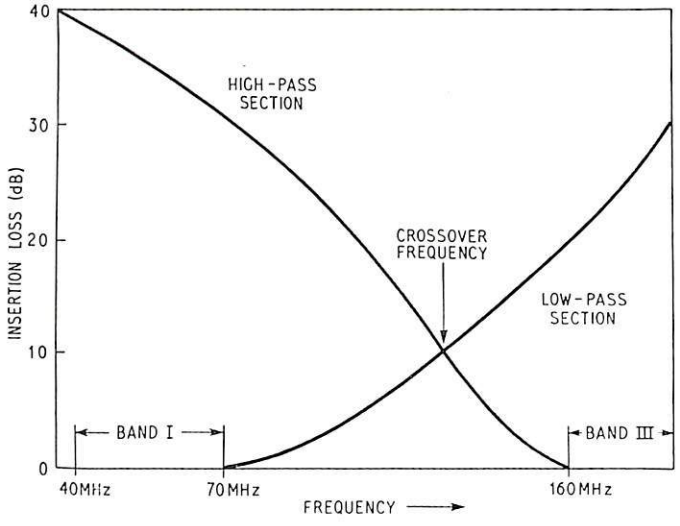


FIG. 5.10. *Performance curves of a typical diplexer.*

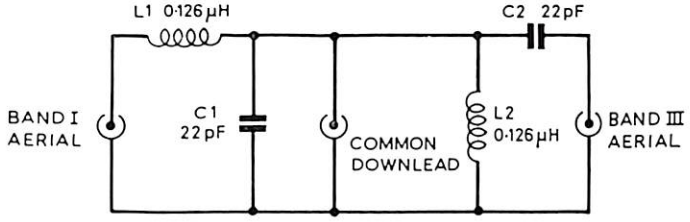
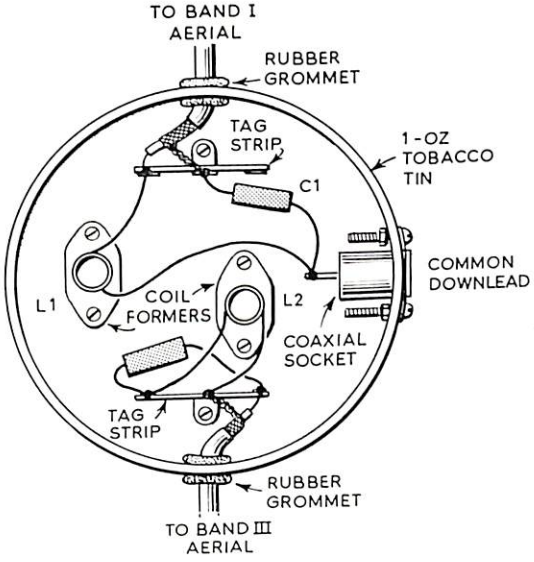


FIG. 5.11. *Half-section diplexer for Bands I and III. Design formulae are:* $L1 = L2 = Ro/2\pi fc$; $C1 = C2 = 1/2\pi fcRo$, *where Ro is the terminal impedance and fc the "crossover frequency". The component values indicated are for a crossover of* 95 *MHz.*

FIG. 5.12. *A simple diplexer can be built into a one-ounce tobacco tin. The circuit is that in* FIG. 5.11. *L1 and L2 are made by close-winding four turns of* 26 *s.w.g. enamelled-covered wire on* $\frac{1}{4}$*-in. diameter polystyrene formers. The wire can be secured to the formers with a cement made by dissolving a piece of polystyrene in a little benzine. The filters can be peaked for the best results by adjusting the turns spacing of the inductors while observing a picture. Mica or ceramic capacitors of* 5 *per cent tolerance can be used for C1 and C2.*



Aerial filters often use T-section networks, and high- and low-pass networks of this nature are shown in Fig. 5.8 (*a*) and (*b*) respectively. These filters combined to form a diplexer are shown in Fig. 5.9, and the component values given are typical for this type of network. The curves in Fig. 5.10 show the general performance of a correctly matched diplexer in terms of insertion loss of the two filter sections over the two bands. The insertion loss of the high-pass section falls to a very low value from Band III upwards, being very high at Band I frequencies, while the insertion loss of the low-pass section falls to a very low value from Band I downwards, being very high at Band III frequencies.

A HOME-MADE DIPLEXER

A somewhat simplified version of a diplexer is given in Fig. 5.11 in which "half-section" filters are employed. These are possible in this application

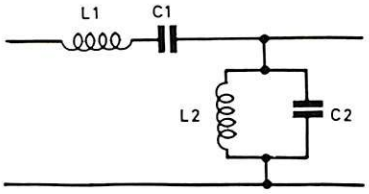


FIG. 5.13. *Bandpass constant-k filter section. Design formulae are:* $L1 = Ro/\pi(f_1 - f_2)$; $L2 = Ro(f_1 - f_2)/4\pi f_1 f_2$; $C1 = L2/Ro^2$; $C2 = L1/Ro^2$, *where Ro is the impedance and* f_1 *and* f_2 *the upper and lower cut-off frequencies in Hz.*

because of the wide separation between the Band I and Band III frequencies —something like 140 MHz—allowing a gentle slope up to cut-off. For a cross-over frequency of around 95 MHz, the values indicated on the circuit should be used, and how these are derived can be gleaned from the caption of Fig. 5.11. Such a diplexer can easily be built into a one-ounce tobacco tin, as shown in Fig. 5.12.

Now, when Band II is to be added, to produce a triplexer, an extra filter section is required. This is called a "bandpass section" because it has to offer very little attenuation (insertion loss) to signals falling between two critical frequencies (i.e., between the top of Band I and the bottom of Band III) and a high attenuation to signals either side of the critical frequencies. Thus, the bandpass section will pass into the common downlead the Band II signals only, and any Band I or Band III signals picked up by the Band II aerial will not get into the downlead. Conversely, owing to the high attenuation ratio through the high- and low-pass filter sections to Band II signals, any Band II signal picked up by the Band I and Band III aerials will not get into the downlead. In that way, therefore, each aerial of the system is in signal isolation.

The circuit of a bandpass filter section is given in Fig. 5.13, and the caption reveals how the component values can be calculated for any requirement.

TRIPLEXER CIRCUIT

This filter section added to an integrated high-pass/low-pass network forms a triplexer, the full circuit of which is given in Fig. 5.14.

A v.h.f./u.h.f. filter or diplexer adopts similar principles to a Band I/Band III diplexer, but the crossover frequency and the component values differ. The crossover frequency of a simple v.h.f./u.h.f. aerial crossover filter (using the circuit and design considerations of that in Fig. 5.11) is 335 MHz. Owing to the ultra high frequencies involved, special care must be given to the construction and design of such a filter to ensure that the insertion losses are as small as possible, particularly on the u.h.f. channels.

The aerial technician should be fully conversant with filters of the nature described and appreciative as to how they can be used for special aerial system applications. For example, it may be required to filter the v.h.f. signals at the

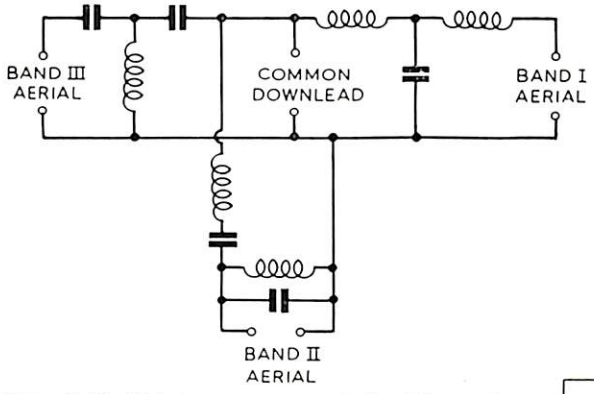
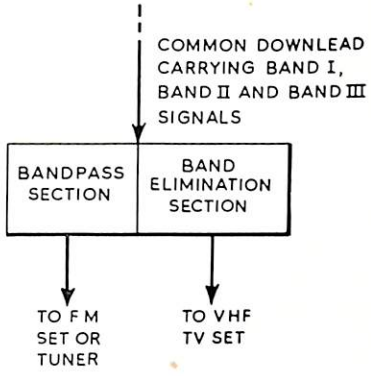


FIG. 5.14. *Triplexer system derived from three filter sections: high-pass for Band III, bandpass for Band II and low-pass for Band I. These can easily be identified in the circuit, and the component values can be obtained from the design formulae given in the captions to* FIGS. 5.8 *and* 5.13.

(Below) FIG. 5.15. *When it is required to group the f.m. and television signals at the end of a common downlead, an integrated bandpass elimination filter system is needed, as shown here.*



end of a downlead into two groups, one for an f.m. receiver or tuner and the other for a television receiver. This is accomplished by the use of an integrated filter section at the set end of the downlead, as shown in Fig. 5.15. One section of this filter is of bandpass mode (Fig. 5.13), passing the Band II signals only to the f.m. set, while the other section is a "band elimination" or "band stop" filter which passes only the Band I and Band III television signals while attenuating or "stopping" the Band II f.m. signals.

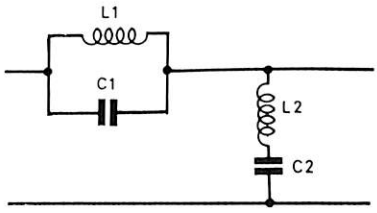
BAND ELIMINATION FILTER

The circuit of a band elimination filter is given in Fig. 5.16 and the caption tells how the component values can be calculated.

When the common downlead carries u.h.f. signals in addition to v.h.f. signals in Bands I, II and III, the u.h.f. signals can be extracted in isolation by the use of a v.h.f./u.h.f. filter prior to the bandpass/band elimination filter system, as shown in Fig. 5.17.

We have already seen how f.m. Band II signal can be fed into a common

FIG. 5.16. *Circuit of band elimination filter section. The component values can be calculated from the following formulae to suit any condition:* $L1 = Ro(f^1 - f^2)/\pi f_1 f_2$; $L2 = Ro/4\pi(f_1 f_2)$; $C1 = L2/Ro^2$; $C2 = L1/Ro^2$, *where Ro is the impedance in ohms and* f_1 *and* f_2 *the upper and lower cut-off frequencies in Hz.*



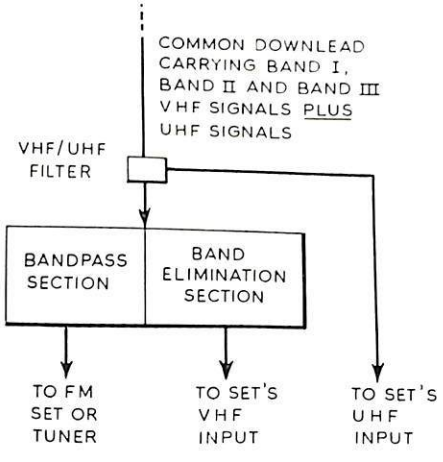
downlead via a triplexer at the top of the downlead. However, a triplexer has three inputs, one for the Band I aerial, one for the Band III aerial and one for the Band II aerial, and ideally all these inputs should be used to ensure correct matching. Television/f.m. diplexers, however, are available commercially.

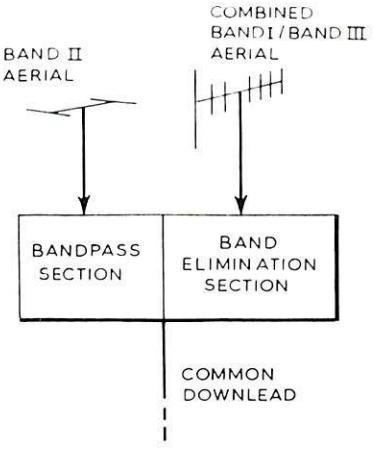
This presents a complication where a combined Band I/Band III television aerial is employed, and it is required to add Band II, as such an aerial has just a single output, the signal combining to this being achieved electronically by the nature of the aerial's design. A solution is to use a bandpass/band elimination filter system (as in Fig. 5.15) in reverse, as shown in Fig. 5.18. If it is required also to add u.h.f. signals to this system, a v.h.f./u.h.f. filter should be introduced after the "FM/TV" diplexer arrangement of Fig. 5.18.

Integrated filters can be used in reverse for grouping the signals in a common downlead or feeder cable to separate outlets. We have already seen how this is done in one application (Fig. 5.17), and Fig. 5.19 shows the use of a diplexer and triplexer in reverse at (*a*) and (*b*) respectively. Grouped outputs may be required for isolated amplification or attenuation, as described later and in Chapters 6 and 7.

SIGNAL SHARING

Provided the signals are of sufficient strength in the downlead, it is possible to direct them into two or more circuits so as to operate more than





(Left) FIG. 5.17. *When the common downlead is also carrying u.h.f. signals, these can be grouped by the use of a v.h.f./u.h.f. filter.* (Right) FIG. 5.18. *To introduce f.m. signal from a Band II aerial to a common downlead when the television aerial consists of a combined Band I/Band III array, a bandpass/band elimination filter system should be used at the aerial end of the feeder.*

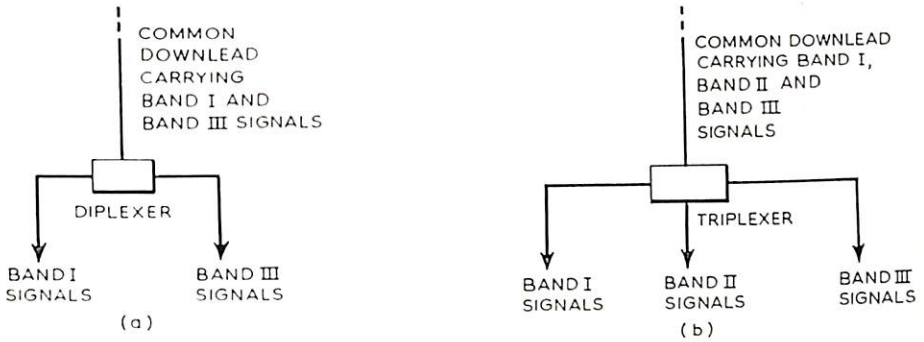


FIG. 5.19. *The v.h.f. signals can be grouped by the use of a diplexer* (a) *or a triplexer* (b) *connected in reverse.*

one receiver simultaneously. When signals are shared in this way, however, they are reduced fundamentally in strength, depending on the number of outlets.

It is not possible technically to tee off the main downlead to other subsidiary feeders, for to do so would almost certainly incite severe mismatch conditions and interaction effects between the sets connected to such a system. Each feed taken from the main feed must itself be matched and the arrangement must be such that the main feeder matching is also retained. One way these conditions can be satisfied is by the use of a resistive "splitter" or "star network", as it is sometimes called.

The circuit of a basic network of this kind is given in Fig. 5.20. Here it will be seen that the outer conductors (braids) of all the feeds and the main downlead are connected together and that each inner conductor is connected to a resistor. Thus, each outlet and the input is connected to a resistor. The resistors ensure that impedance matching is retained all the way round the network, and for a common impedance circuit (that is, where all the feeders have the same characteristic impedance) the resistors have like values, the value being calculated relative to the number of outlets and the common impedance value, as explained in the caption of Fig. 5.20.

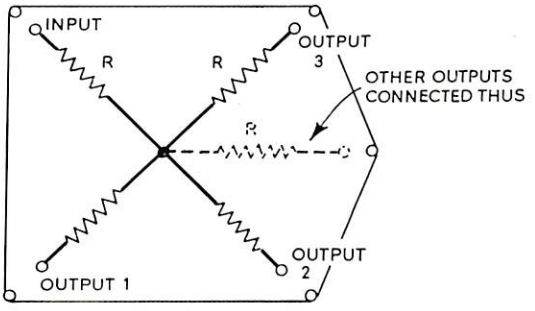


FIG. 5.20. *Basic star network. In a common impedance system the resistors have like values, where* $R = Zo(n - 1)/(n + 1)$, *Zo being the common impedance and n the number of outlets.*

The signal loss to each outlet from the common feeder is governed by the number of outlets. For example, a two-outlet network cuts the signal at the end of the main feeder by half at each outlet. A three-outlet system cuts down the main signal so that only a third of the strength is available at each outlet, a quarter of the signal on a four-outlet system, a fifth on a five-outlet system and so on.

These are the approximate resistive losses and do not take into account the losses in the subsidiary feeders. Moreover, the correct matching is retained only as long as each outlet is "loaded" with the correct value of impedance. Thus, any outlet that is not connected to a receiver must be loaded with a non-inductive resistor equal to the calculated impedance value (about 75 ohms for f.m. radio and television feeders).

A HOME-MADE SIGNAL SPLITTER

It is quite a simple matter to make up a splitter unit of this kind and, again, a one-ounce tobacco tin makes a convenient housing for a two- or three-outlet splitter, as shown in Fig. 5.21. A two-ounce tin is more practical when a greater number of outlets are required. Carbon composition, non-inductive $\frac{1}{4}$ or $\frac{1}{2}$ watt resistors should be used.

A simple type of star splitter is suitable for v.h.f. signals up to about 250 MHz, but beyond this frequency into the u.h.f. bands the construction needs to be more specialized to avoid the signal bypassing the resistors due to the capacitances of the wiring, components and circuit. The inductance of the wiring also becomes very important at u.h.f. Special u.h.f. splitters are available commercially for more exacting jobs.

It must also be remembered that over fairly long feeder runs, the u.h.f.

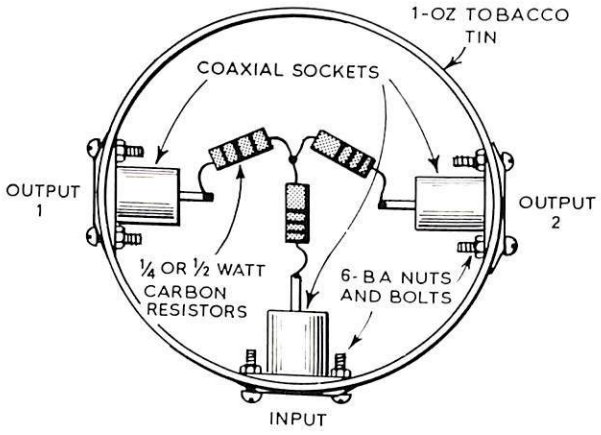


FIG. 5.21. *A simple two- or three-way signal splitter can easily be made up and accommodated in a one-ounce tobacco tin.*

and Band III signals will be weakened due to the cable losses to a greater extent than the Band II and Band I signals. Signal sharing over long tracks of cable, therefore, should not be attempted without amplification unless the strengths of the signals over the various bands are sufficient at the splitter outlets to stand further weakening by the cables.

In many areas it is possible to split the v.h.f. signals in a common downlead two ways while still retaining sufficient signal on Bands I, II and III to provide reasonable signal/noise performance of two simultaneously working receivers; but whether this is possible on the u.h.f. channels depends very much on the local u.h.f. signal conditions. It is often necessary to optimize the u.h.f. aerial system to obtain a reasonable signal/noise performance on just one receiver, meaning that by dividing the u.h.f. signal by two (for two outlets) reception is likely to be far from adequate. In this case it would be desirable to introduce an amplifier into the system to boost the u.h.f. signals. Similar amplifiers for the other bands would be necessary should the attenuation of the splitting process be too great for the available common feeder signal.

USING SIGNAL AMPLIFIERS

Fig. 5.22 shows how the signal circuits can be opened by means of filters for the introduction of appropriate signal amplifiers. Here each of the five outlets delivers signals in Bands I, II, III and u.h.f. The degree of amplification in each band is governed by the strength of the signals in the common downlead or feeder and by the insertion loss of the splitter which, as we have seen, depends on the number of outlets.

As a simple illustration, supposing the signals at the end of the common downlead were of sufficient strength to operate one set adequately, and that it was required to work three sets. A three-way splitter would be used, meaning that only one-third of the feeder signal would arrive at each set from the splitter. This represents a signal loss of the order of 10 dB, so if amplifiers were used and each one had a gain of 10 dB the splitter losses would be countered and each set would receive signals equal in strength to those at the end of the common feeder.

If the cables feeding the set were extra-long, then the amplifiers would be arranged to give a somewhat greater gain to combat the cable losses as well as the splitter losses. Since the cable losses are greatest at the higher frequencies, for correct signal balance at each cable output, the gains of the amplifiers should be arranged to rise progressively from Band I to u.h.f., by an amount depending on the length of the various feeders. In practice, however, slight signal unbalance is taken care of by the automatic gain control systems in the receivers themselves.

Instead of using three separate amplifiers for Bands I, II and III a single

wideband amplifier could be used, as shown in Fig. 5.23. Alternatively, if it is not required to carry Band II signals on the system, a dual-band (Band I/Band III) amplifier could be used, as shown in Fig. 5.24.

If the u.h.f. signals arrive on a separate downlead from the aerial system, then the first v.h.f./u.h.f. filter would not be required, but in all cases such a filter would be needed at each outlet to supply dual-standard sets, as shown in Fig. 5.25. The system could, of course, be run on v.h.f. alone, in which case the u.h.f. circuits would be eliminated.

V.H.F. TRANSISTOR AMPLIFIER

Transistor amplifiers, owing to their low noise feature, are becoming popular in signal sharing systems, and the circuit of such an amplifier for the v.h.f. channels is given in Fig. 5.26. This has a power gain of the order of 10 dB and is suitable for any channel in Band I, any channel in Band III with a bandwidth of 4 to 5 MHz, or for the whole of Band II, as governed by the

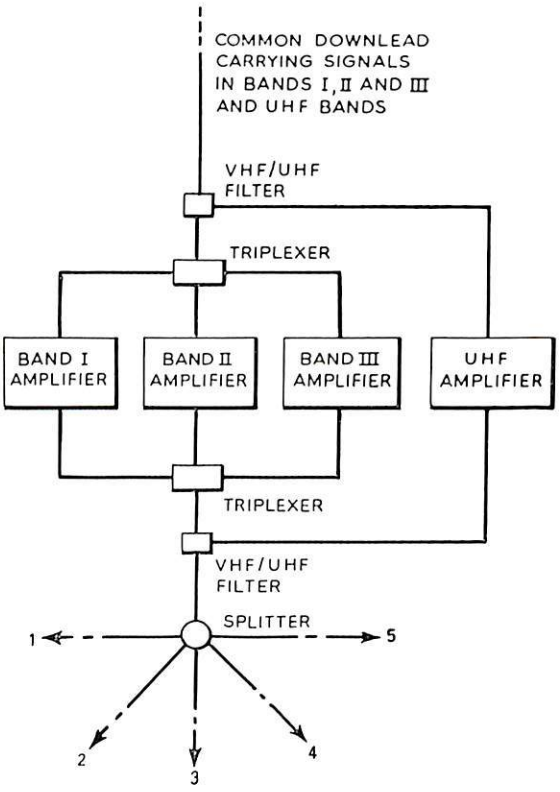
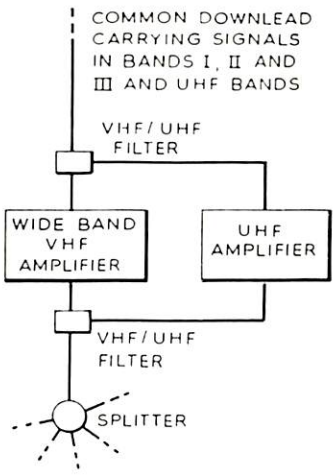
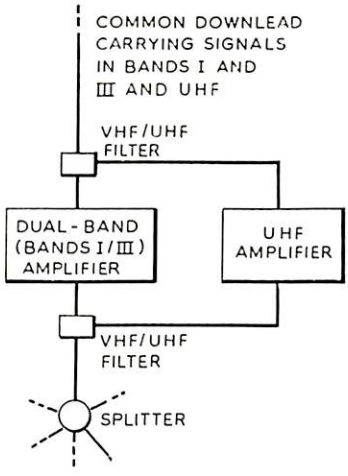


FIG. 5.22. *To combat splitter and feeder losses in a shared signal system separate, independently tuned amplifiers, such as the kind shown in* FIG. 5.26, *can be employed.*





(Left) FIG. 5.23. *Instead of three separate amplifiers, a wideband amplifier can be used for the v.h.f. signals in Bands I, II and III.* (Right) FIG. 5.24. *Where Band II f.m. is not required, a dual-band (Bands I and III) v.h.f. amplifier can be used. In all cases, however, where u.h.f. signals are carried, the u.h.f. amplifier should have a bandwidth sufficient to cater for all the channels of a local group of transmitters (about* 100 *MHz).*

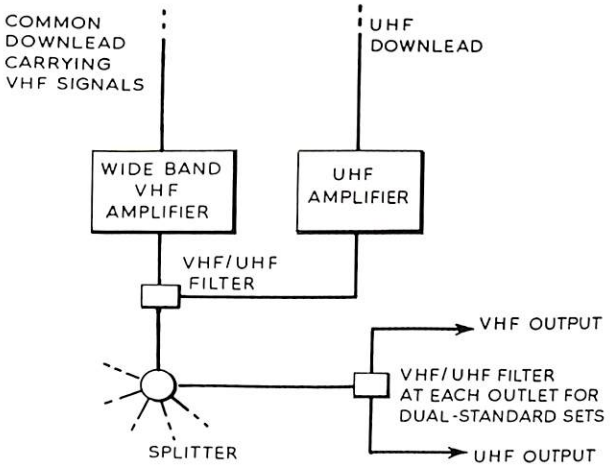


FIG. 5.25. *When a separate downlead is used to carry the u.h.f. signals the first v.h.f./u.h.f. filter* (FIGS. 5.22, 5.23 *and* 5.24) *is not used, but this is required for adding the u.h.f. signals after amplification. A filter is also needed at the end of each connecting lead to facilitate the use of dual-standard sets on the system.*

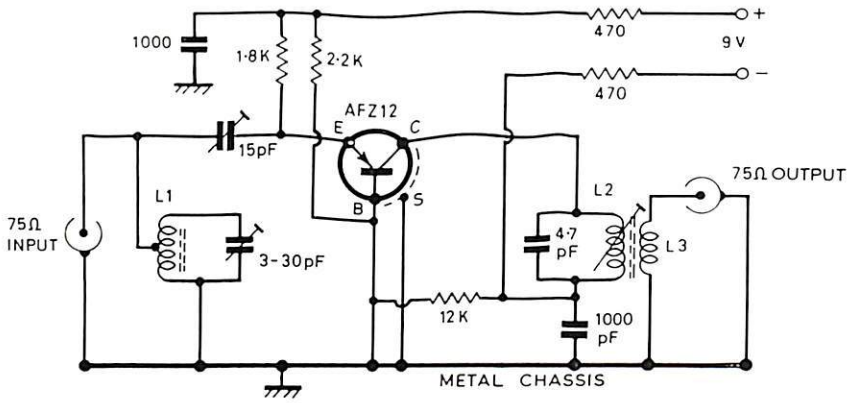


FIG. 5.26. *Circuit diagram of common-base v.h.f. transistor amplifier suitable for small signal-sharing systems. L1, L2 and L3 are wound on ¼-in. diameter formers of number of turns to suit the required channel. The number of turns on L3 determines the overall gain and bandwidth. The amplifier should be built into a metal case for adequate screening.*

input and output tuned circuits. The amplifier should be constructed in a screened case and can be run either on a small 9 volt battery or from a mains power unit, the current consumption being not much in excess of 2 mA.

For the u.h.f. channels the amplifier has to be more specialized, and details of an amplifier of that kind are given in Chapter 6.

In cases where it is required to operate just one receiver in two or more rooms, signal splitting techniques are not necessary, for extension cable systems can be evolved quite easily to couple in lengths of cable from the main signal outlet to the other rooms as shown in Fig. 5.27. On no account should signal carrying cables be connected in parallel without the use of matching pads or splitters.

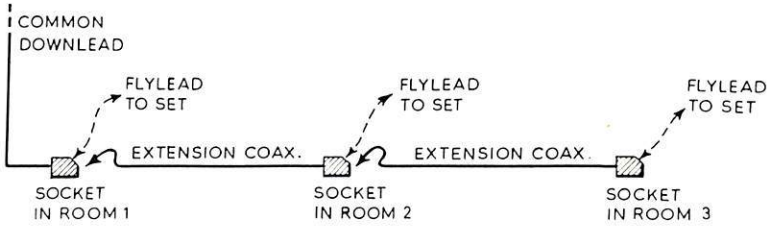


FIG. 5.27. *Where it is required to have signal facilities in two or more rooms, with one set only on the system, a splitter network is not required for the signal can be conveyed to the various rooms through extension cables as shown. For instance, to operate a set in room 3, the extension cables are plugged into sockets 1 and 2. This method avoids connecting signal-carrying cables in parallel, which is highly undesirable and technically incorrect.*

CHAPTER 6

Signal Boosting and Booster Amplifiers

As radio communications systems generally have developed, so have receivers become more and more sensitive. Early television receivers, for example, required 200-300 μV of aerial signal for a picture of reasonable viewing quality. Today's sets give a similar picture for an aerial signal of only 50 μV or so, depending on the signal frequency.

It is not particularly difficult to step up the sensitivity of any receiver by adding more amplifying stages: basic sensitivity, however, is not the key to the problem. Sensitivity is usually given as so many microvolts of signal input required to give a specific level of audio output in the case of a sound receiver, or a specific level of video signal drive to the picture tube in the case of a vision receiver.

Thus, a receiver may be said to have a sensitivity of, say, 100 μV. By putting in front of such a receiver an amplifier which steps up the signal voltage ten times (20 dB voltage gain), the basic sensitivity of the combination (looking in at the amplifier input) would be increased to 10 μV. This means that an input signal of 10 μV would produce the required or specified audio or video output.

Unfortunately, this is by no means all the story, for when a signal is amplified the amplifier device and its circuits add a spurious signal to the wanted signal. This spurious signal is called "noise signal" or, more generally, just "noise"; it has been discussed already in Chapter 1.

NOISE

Noise in electronic devices results essentially from the random movement of electrons in conductors. Electrons (and current carriers generally) in conductors have a tendency to interchange between neighbouring atoms, but the net effect always averages out to that of electrical balance. Nevertheless, when an electron moves there is said to be a flow of electricity. Electric batteries, dynamos, generators and so forth all work by causing an orderly movement of *electrons* from negative to positive through the conducting

medium (the conventional flow of electricity is considered as from positive to negative, but the true flow is in reverse).

The random movements of electrons, although adding up to zero charge, produce instantaneous variations in potential across a conductor. This potential or voltage fluctuation, as it were, represents the noise voltage or noise signal. Noise voltage is very small indeed, detectable only by high-gain amplifying equipment. It thus becomes important when the signal proper is very weak and high-gain amplifiers are used to step-up the weak, wanted signal.

Noise is composed of transient-type waveform created from a wide range of frequencies from low to very high values. Owing to its wide frequency spectrum it is sometimes given the term "white noise", by analogy with white light which is composed of all the colours of the spectrum. If noise signal is amplified sufficiently it can be heard as a "hiss" from headphones or loud-speaker, or it can be seen on the screen of an oscilloscope as a band of illumination with poorly defined parallel edges due to the random nature of the individual pulses of noise, as shown in Fig. 6.1.

Now, a receiver not only produces its own noise but it is also fed with noise signals from the aerial, because the aerial is a conductor and therefore produces noise signals itself. The temperature of the conductor has an effect on the noise signal level, because as the temperature is increased the electrons moving at random from atom to atom are agitated and increase in number, so increasing the noise voltage.

Noise is also picked up by the aerial in terms of radiations from outer space, as distinct from locally generated interfering signals. Assuming, then, that the amplifying equipment in the receiver could be made completely noise-free (which is impossible), there would still be aerial noise and noise signals from outer space. The strength of these noise signals, however, is very small under normal conditions compared with those produced by the amplifier and electronics of the receiver. For practical purposes, therefore, cosmic and aerial noise can be discounted.

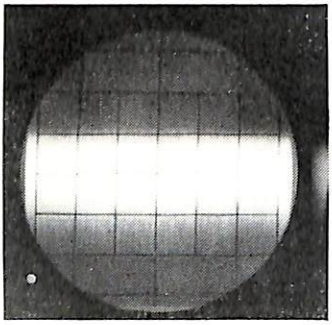


FIG. 6.1. *Noise as displayed on the screen of an oscilloscope.*

Since the advent of electronics in communications it has for ever been the aim of the designer to reduce the noise created by his equipment. The threshold level below which the wanted signals cannot be picked out from the noise is generally defined as when the power of the wanted signal at the output of the receiver *equals* the output noise power; that is, when $(S/N)_{out} = 1$, where S

is the output signal power and N the output noise power. This threshold would exist, for instance, in the case of an amplifier which lifted the aerial signal to a level of 1 volt, but which at the same time created a noise signal at its output also equal to 1 volt. The ideal situation would be for the amplifier to lift the aerial signal to 1 volt without adding any noise signal whatever; but this is not possible.

Of course, there is a signal/noise ratio at the input terminals of the receiver or amplifier, and this we can call $(S/N)_{in}$, where S is the input signal power and N the input noise power. Since the receiver or amplifier is adding noise to the signal it follows that if $(S/N)_{out}$ corresponds to unity then $(S/N)_{in}$ will be greater than unity.

NOISE FIGURE

The noise figure (F_n) of an amplifier can thus be expressed as $(S/N)_{in}$: $(S/N)_{out}$, the ratio being given generally in decibels (see Chapter 1). Since the temperature affects the noise generated, F_n is usually considered at a temperature of about 17 deg. C. (room temperature).

Each section of a receiver has its own individual noise figure in accordance with the expression given above, and the overall noise figure ($F_{n(total)}$) of a number of stages takes into account the noise figures of the individual stages in the manner shown by the following expression:

$$F_{n(total)} = F_{n1} + \frac{F_{n2} - 1}{P1} + \frac{F_{n3} - 1}{P1 \times P2} + \text{etc.},$$

where F_{n1}, F_{n2}, F_{n3}, etc., are the noise figures of the first, second, third, etc., individual stages and P1, P2, etc., are the power gains of the first, second and etc. individual stages or amplifiers.

This expression shows that the first stage (F_{n1} and P1) is of far greater importance than the subsequent stages in keeping $F_{n(total)}$ as small as possible, and for this reason F_{n1} should be as small as possible and P1 as large as possible for the best overall noise figure.

In amplifying systems the power gain of stages subsequent to the first one will be above unity, and for most practical overall noise computations the expression below is sufficiently accurate:

$$F_{n(total)} = F_{n1} + \frac{F_{n2} - 1}{P1}.$$

In the early days low-noise valves were adopted in first-stage or aerial amplifier circuits to secure a reasonable overall noise figure, but even so the noise added to the wanted signal was excessive and on the pictures of television sets operating in areas of low signal field excessive grain or "snow" was present.

As higher and higher frequencies were used for radio and television, so

the noise problem became more serious since the noise figure of an amplifier rises with increase in frequency. The noise figures relating to valved television and f.m. switched and turret-type tuners are of the order of 5 dB on Band I, 5·5 dB on Band II, 6·5 dB on Band III, 12 dB on Band IV and 15 dB on Band V. These figures clearly reveal the noise increase with increase in frequency. Early sets with pentode r.f. amplifier valves and no tuners had even higher Band I noise figures. (Early sets, of course, were single-channel, Band I only.)

The relatively smaller noise figures of modern sets using valved tuners are due essentially to the use of low-noise r.f. amplifier valves such as a double-triode in a cascode circuit or just a single, common-cathode triode valve, the latter now superseding the former due to the advent of high-slope, low-capacitance triodes. Such techniques are described in a companion volume, *Television Servicing Handbook*.

The use of transistors is reducing the noise figures even more, as will be shown later.

EQUIVALENT NOISE SIGNAL

Now, the noise figure of a receiver can be looked upon as an equivalent "noise signal" at the aerial input along with the wanted signal. Suppose, for instance, that the noise signal at the *output* of an amplifier is 100 μV and that the gain of the amplifier is 20 dB, or ten times. One could then view this as a completely noise-free amplifier at the input of which is a noise signal of 10 μV. This signal would be amplified ten times and thus appear at the output as 100 μV. It is sometimes useful to consider an amplifier noise figure in terms of equivalent noise voltage.

For a television picture to be almost completely free from grain due to noise the input signal/noise ratio should not be less than 46 dB (i.e., 200 times). Thus, if the equivalent noise signal is 5 μV, the aerial signal (at the output of the downlead) must be 200 times stronger than this completely to mask the noise. That is, for a signal/noise ratio of 46 dB the aerial signal would have to be 200 times, or 1,000 μV (equal to 1 mV). For the signal completely to mask the "hiss" of noise in the sound channel it needs to be about 40 dB stronger than the equivalent noise signal; that is, 100 times. These are threshold values.

From the foregoing discussions, the importance of a low noise figure should be quite evident, for if the absolute sensitivity of a receiver is, say, 10 μV and the equivalent noise signal is of the same value it would need an input signal some 200 times above the sensitivity voltage to secure optimum signal/noise ratio. The "usable" sensitivity voltage is the important figure, and so far as vision is concerned this can be defined as the input signal voltage necessary to give a signal voltage output which is not less than 30

times above the noise output voltage. This represents about 30 dB signal/noise ratio, and ratios below this produce far too much grain on a picture for reasonable viewing.

With communications systems the signal/noise ratio can be much lower for intelligibility, and signals at signal/noise threshold can often be recognized (i.e., when the output signal power equals the output noise power). But for broadcasting, and vision in particular, the signal/noise ratio should be up to 40 to 46 dB.

We are often faced with the problem of a very weak aerial signal. Modern sets will work "flat out" in an endeavour to extract the optimum information from such a weak signal, meaning that the signal will be accompanied by a relatively high noise voltage and that the limit to amplification will be set by the noise produced by the first stage rather than by its gain.

A stronger signal could be fed to the set by stepping up the weak aerial signal by means of a "pre-amplifier", "aerial amplifier" or "signal booster", as this sort of device may be called. This will tend to improve the signal/noise ratio at the input to the *set*, but whether it will improve the overall signal/noise ratio as viewed from the input to the amplifier—which is the important aspect—will depend just on how much noise the booster is itself introducing.

We can see how much the overall noise figure is improved by using the expression given earlier. Suppose we have an old set with a noise figure on Band I of 18 dB and we use a valve amplifier between its input and the aerial giving a gain of 20 dB (ten times) with a noise figure of 10 dB, how would this improve the overall noise figure?

By putting these figures in place of the symbols of the expression, we get:

$$F_{n(total)} = 10 + \frac{18 - 1}{20} = 10{\cdot}85 \text{ dB}.$$

Thus, the noise figure is improved a little over 7 dB. If the amplifier has a gain of only 10 dB and a noise figure itself of 18 dB, we get:

$$F_{n(total)} = 18 + \frac{18 - 1}{10} = 19{\cdot}7 \text{ dB}.$$

This shows a worsening of the overall noise figure, from the set minus the amplifier of 18 dB to the set plus the amplifier of 19·7 dB. Even if the amplifier has a gain of 20 dB, the noise figure would still be degraded by 0·85 dB. The important factor, therefore, is the noise figure of the booster amplifier.

TRANSISTOR AMPLIFIER NOISE FIGURE

It has been mentioned that modern sets have quite good noise figures; but even these good figures can be improved by the lower noise factor of transistors. A transistor amplifier can easily be made to have a noise figure of about 5 dB on Band III with a gain of 15 dB. We have seen that valved

tuners have a noise figure of about 6·5 dB on Band III, so by the use of such a booster the overall noise figure can be improved to:

$$F_{n(total)} = 5 + \frac{6{\cdot}5 - 1}{15} = 5{\cdot}33 \text{ dB}.$$

In practice, the improvement is usually better than this because as valved tuners age, so their noise figure rises; but this does not happen to the same degree with transistor amplifiers. Moreover, with special care the noise figure of a transistor amplifier at 200 MHz can be made as low as 3·9 dB with good input matching. In the above example, this would reduce the overall noise figure to 4·32 dB, a very worthwhile improvement, even on Band III.

On Bands I and II some improvement is generally possible to the overall noise figure, but is less startling than at the higher frequency channels because of the lower noise figure of valved tuners at the lower channel numbers. Nevertheless, the improvement can be dramatic where the valved tuner happens to be badly worn.

The most dramatic improvement is observed on the u.h.f. channels when a transistor booster amplifier is connected to a u.h.f. valved tuner. Transistor booster amplifiers can be designed with a noise figure as low as 5 dB and a gain of 14 dB at 500 MHz. At that frequency a valved tuner may have a noise figure of around 14 dB. The improvement is thus given by:

$$F_{n(total)} = 5 + \frac{14 - 1}{14} = 5{\cdot}9 \text{ dB}.$$

That is, an improvement of 8·1 dB, from 14 dB to 5·9 dB. This is a remarkable improvement, as will be appreciated, and can make the difference between a picture that is too noisy to view and one which is reasonably viewable.

Improvement is still possible when the receiver employs a transistor u.h.f. tuner (or an integrated "all-band" transistor tuner). Such a tuner may have a noise figure of about 8 dB (or more) at 500 MHz, so the improvement given by a transistor booster amplifier with a gain of 14 dB and a noise figure of 5 dB is:

$$F_{n(total)} = 5 + \frac{8 - 1}{14} = 5{\cdot}5 \text{ dB}.$$

This represents an improvement over the set alone of 2·5 dB.

In all the cases so far considered it is assumed that the booster amplifier is located close to the parent receiver, with a short length of coaxial cable connecting the output of the booster to the aerial socket of the set. The foregoing thus dispels any doubt that may exist as to whether a set-side transistor amplifier is a worthwhile proposition. It certainly is in a large number of cases, not only on the u.h.f. channels, but on the v.h.f. channels as well.

It is sometimes said that a booster amplifier is useful only when mounted close to the aerial, and when acting as a masthead amplifier. We can see now

that this is not specifically true. From the aspect of overall *noise figure* it matters little whether the amplifier is mounted close to the aerial or close to the set. It is far more convenient at the latter location. This is not to say, however, that mounting the amplifier close to the aerial does not endow the system with overall advantages. Indeed, there is much to be said for the masthead mounting of a transistor amplifier, particularly at u.h.f. Why is this?

Well, the signal/noise ratio at the input of an amplifier, as we have seen, is related to the equivalent noise signal. The stronger the wanted signal or the smaller the equivalent noise signal, the better the signal/noise ratio, and it is the signal/noise ratio that controls the amount of grain showing on a picture and the amount of "hiss" heard from the speaker.

By mounting the amplifier close to the aerial all the signal available at the terminals of the aerial is conveyed straight to the amplifier instead of suffering loss by travelling to the amplifier through the downlead. This in itself improves the input signal/noise ratio quite considerably, depending on how much signal would have been lost in the downlead (i.e., its length and attenuation factor) had the amplifier been connected at the set end.

On the debit side, however, the improvement is a little less than might be expected because the loss of output signal in the downlead is the same as a reduction in gain of the amplifier. Thus, if the amplifier has a gain of 14 dB and the loss in the downlead is 4 dB, from the overall noise figure aspect, the amplifier should be considered to have a gain of 10 dB and not 14 dB. But this does not make a great deal of difference.

A further advantage of masthead operation is that any interfering signals picked up on the downlead are not amplified before being applied to the set, as they would be with the amplifier connected at the set end of the downlead. But this is not all that important, and experiments carried out by the author over several years indicate that masthead mounting is highly desirable at u.h.f. when the downlead is fairly long and not of super-low-loss characteristics.

On the v.h.f. channels—and on the u.h.f. channels when the downlead is no longer than an average run and of good-quality, low-loss characteristics—the mounting of the amplifier (assuming one is required) close to the set is adequate in the majority of cases. And, of course, such siting relieves the complications of waterproofing and feeding power to the amplifier through the downlead.

WHEN IS A BOOSTER AMPLIFIER REQUIRED?

A transistor booster amplifier is worth considering when:

(1) the noise figure of the set's tuner is high, showing as grain on the picture and "hiss" on the sound;

(2) the aerial signal is weak, giving symptoms as in (1) or lack of picture contrast and weak sound;

(3) it is not possible to employ a complex outdoor aerial as the prevailing signal conditions really dictate (for instance, outdoor aerials are prohibited by some councils, in which case a simple attic-type aerial may have to be employed, and the signal from this can be lifted by a booster amplifier);

(4) it is required to receive distant v.h.f. or u.h.f. stations (i.e., for DX activities);

(5) it is required to operate more than one receiver simultaneously from the aerial system (see Chapters 5 and 7);

(6) multipath interference is troublesome and the aerial signal is considerably weakened when the aerial is orientated for the best signal/multipath interference ratio (in this case the weak wanted signal, resulting from turning the aerial off beam to minimize the ghosting, is brought back to a usable level without the interference by the use of a booster amplifier).

There are other times when a good, low-noise transistor booster amplifier may prove advantageous, such as to enhance the basic sensitivity of an old set which on the available aerial signal is incapable of delivering sufficient video drive to the picture tube for a fully contrasted picture. In this case, noise may not be the chief consideration, for the aerial signal may be relatively strong, thereby giving a reasonable input signal/noise ratio and yet insufficient for full drive.

Modern receivers embody quite efficient sound and vision automatic gain control (a.g.c.) systems. These hold the output of the sound and vision channels constant over a wide range of input signal levels. Thus, the addition of a booster amplifier will not generally increase the sound or vision output (unless the aerial signal is very weak or the sensitivity of the set very low), but it will certainly reduce the picture grain content and any sound "hiss."

Of course, no booster amplifier will combat general defects of the receiver. It will not, for instance, increase the service of a worn picture tube; indeed, the extra video drive provided by the booster will tend to push the tube harder into its overload state—resulting from the wear—and emphasize the fault symptom rather than correct it. On the other hand, a set with weak tuner and i.f. amplifier valves would probably work better due to the extra gain given by the booster, this compensating for the gain lost due to the weak valves.

F.m. Boosting. Low-noise transistor signal boosters can also prove useful on Band II, in front of f.m. receivers and tuners. The advantage here is not so much overall noise figure reduction, but the extra signal boost given by the amplifier ensures that the set or tuner amplitude limiting circuits are pushed really hard-on, resulting in a considerable reduction of background noise in areas of high interference level and fairly weak signal field. An f.m. booster also allows good reception from simple aerials that would not otherwise work the set or tuner properly, due to lack of amplitude limiting.

The use of an f.m. booster also makes it possible to receive distant v.h.f. f.m. stations that would not normally be received by the set alone, and can enhance the quality of stereo sound.

M.W. and L.W. Boosting. Medium- and long-wave signal boosting is desirable for transistor portables operated in the heavy internal interference environment of motor cars. Their application is discussed in Chapter 3. The King Karad Booster is a specially designed h.f. amplifier suitable for this purpose, illustrated in Fig. 3.37.

It is possible to extend the boosting into the short-wave bands, and extremely good gain figures can be achieved with transistors in current production.

Transistor boosters integrated with an aerial system are described in Chapter 3, and examples of set-top aerials having dual-band transistor amplifiers in their bases are shown in Figs. 3.33 and 3.34.

FITTING BOOSTER AMPLIFIERS

Transistor booster amplifiers need care in connection. They are designed for a nominal input and output impedance of 75 ohms, but if the input or output load impedance tends to swing reactive (i.e., away from the ideal resistive state), instability and poor gain can result, depending on the "stability margin" of the amplifier.

Unfortunately, the end of a downlead does not always "look" to the amplifier input exactly resistive due to aerial mismatch effects or poor or joined feeder cable. Likewise, the aerial terminal of a receiver may not be purely resistive and 75 ohms on all channels.

Thus, there is the possibility of the amplifier being mismatched, and while this may not always cause instability it can affect the amplifier response characteristics. The amplifier output can be partially "buffered" from the effect of changing impedance at the set's aerial socket by the use of a fairly long length of coaxial cable from the output of the amplifier to the aerial socket of the set. A length of about 10 ft can be used to advantage, but in some cases quite an improvement can be achieved by adjusting the length of this connecting cable for the best signal transfer from amplifier to set.

Similar reasoning applies to the downlead to the input of the amplifier. If this is reactive, its characteristic impedance can be restored by reducing its length $\frac{1}{2}$ in. or so at a time until the best reception and stability results on the channels in use.

Some masthead amplifiers require a certain length of cable from their "input" to the aerial dipole terminals to avoid distortion of the response characteristics.

It is possible to "swamp" adverse source impedances by shunting the input and output terminals of the amplifier with a 100 ohm resistor. This is

not generally desirable, however, because each resistor will lose about 3 dB of gain, resulting in a 6 dB gain reduction if two resistors were used. It is far better to match by adjusting the length of the input and output cables to achieve a 70 to 75 ohms resistive characteristic, as explained earlier.

DANGER OF ELECTRIC SHOCK

It is also a good idea to make sure that the "neutral" mains power supply lead to the set (connecting to the metal chassis or h.t. negative line of the receiver) is, in fact, connected to the neutral pin on the mains plug. This is the proper way to wire any receiver, of course. Wiring the other way round makes the receiver chassis (or h.t. negative line) "live" with respect to earth, which can be dangerous, though sets are protected electrically in this event by adequate insulation and isolation components.

One isolating system is in the set aerial circuit. Here capacitors of around 500 pF are connected in series with the set input circuits which, with the mains supply connected the wrong way round, could be "live" to earth. These capacitors ensure that any mains supply currents resulting from the incorrect connection of the set to the mains are of very small magnitude should the aerial be connected to earth. They can fail, though, and there have been numerous reports of aerial erectors having received electric shock from touching an aerial which is connected to the "live" side of the mains supply by incorrect mains connection at the set and failure of an isolating capacitor. The return mains circuit is then through the erector's body!

The best plan is always to disconnect the aerial plug from the set's aerial socket before making any adjustments to the aerial system, for although there may not be a leak through an isolating capacitor, the reactance lets through just a little current at 50 Hz and can produce a slight electrical sensation, which could prove disconcerting on a roof in wet weather if the aerial happens to be well insulated from earth and the capacitor charging current is directed through the body of an operator touching the aerial.

If the aerial is earthed it is often possible to see a small spark when the downlead plug touches the aerial socket—that is, when the connection here is made and broken for this purpose. This effect means that the mains to the set is incorrectly connected, though it does not necessarily indicate that an isolating capacitor's insulation has collapsed. In this event, and with an earthed aerial system and round-the-wrong-way mains to the set, a very large spark would occur that would almost certainly damage the set or blow a fuse.

TRANSIENT PROBLEMS

The foregoing brings us to the point that transient-producing sparks of this nature, even small ones, can ruin the transistor in a booster amplifier

should this be connected to a "live" chassis set and earthed (or partially earthed) aerial system. It is a good idea to earth the aerial system, but it is definitely not a good thing to run any set of the a.c./d.c. type with the mains connected incorrectly.

Static discharges, such as are produced by nearby lightning flashes, can also create transient currents of sufficient magnitude to damage the transistor in a booster amplifier. For this reason it is wise to disconnect a booster during an electrical storm, but this is impossible if it happens to be located at the top of the aerial mast.

Having considered signal boosting in all its aspects, it is now proposed to investigate circuits and designs for v.h.f. and u.h.f. transistor booster amplifiers.

V.H.F. AMPLIFIER DESIGNS

Fig. 6.2 shows a circuit design by Mullard for a Band III v.h.f. amplifier. Here a Mullard AFZ12 transistor is used connected in the common emitter mode with the input signal applied to the base (more recent p-n-p or n-p-n versions can be used by adjusting the supply polarity and resistor values accordingly) L1 and C1 tune the input signal, and the tap on L1 in conjunction with C2 transform the 75 ohm input impedance to a value suitable for the base of the transistor. R1 and R2 serve as a potential divider to bias the base for the value of forward emitter/base junction current giving the best noise figure. R3 is the ordinary emitter resistor and C3 its bypass capacitor. R4 and C4 are decoupling components, desirable for optimum stability.

Output tuning and matching are taken care of by L2 and C5 in conjunction with C6. This network steps down the collector impedance to 75 ohms.

The noise factor of a well-designed version of this amplifier can be as low as 3·9 dB at 200 MHz with a gain of 11 dB over a bandwidth of 5 MHz.

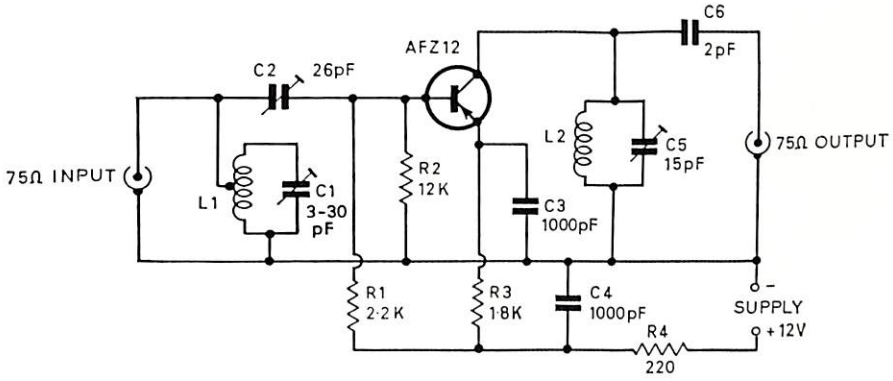


FIG. 6.2. *Circuit diagram of Band III common-emitter amplifier. Coil details are given in the text.*

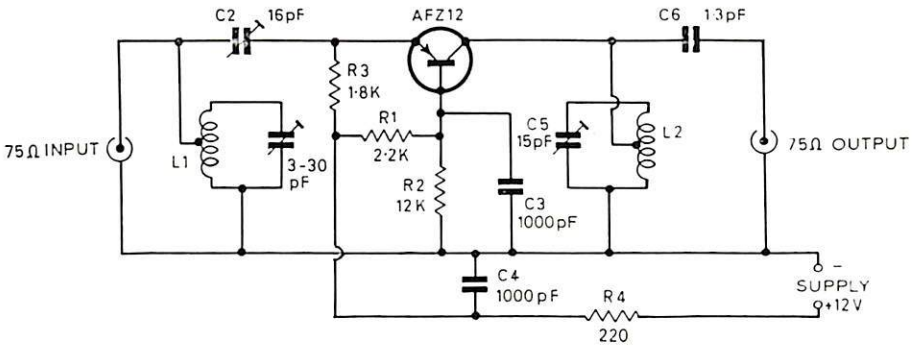


FIG. 6.3. *Circuit diagram of Band III common-base amplifier. Coil details are given in the text.*

Another Mullard circuit using the same transistor but this time in a common-base circuit is shown in Fig. 6.3. Here the same types of input and output tuning and matching are used, but with the input matching capacitor (C2) altered in value to suit the lower impedance at the emitter.

L1 in both circuits consists of a coil of rather less than 2 turns of 18 s.w.g. copper wire with 1 cm outside diameter. The tap to the input is at a half-turn from the lower end of the coil. L2 in both circuits consists of a coil of $2\frac{1}{2}$ turns of 18 s.w.g. copper wire with 1 cm outside diameter.

The common-base circuit should yield a noise figure of about 5·5 dB and a gain of about 12·5 dB at a bandwidth of 2·7 MHz. The gain and noise figures depend to some extent on the emitter current, and with the AFZ12 transistor a fair compromise between power matching at the input and noise performance can be attained with an emitter current of around 1 mA.

Care must be taken in the component layout of the amplifier to ensure the best possible screening between the input and output circuits. Unless this screening is really efficient there will be a tendency towards positive feedback with consequent instability. Further, the power supply should be filtered to avoid the occurrence of a common impedance coupling between different parts of the circuit.

Screening between the input and output circuits can be achieved by mounting a thin copper strip between the transistor collector and base leads, or between the collector and emitter leads in the case of the common-base amplifier. Extra protection is given by mounting the input and output coils either side of the metal chassis upon which the amplifier is built.

U.H.F. AMPLIFIER DESIGNS

Next, we may consider Mullard designs for two different versions of a u.h.f. transistor booster. One version is suitable for mounting at the receiver

end of the downlead and the other is for masthead mounting. The circuit and mechanical design of the former are given in Fig. 6.4 at (*a*) and (*b*) respectively, while those of the masthead version are given in Fig. 6.5 at (*a*) and (*b*) respectively.

The amplifier has a bandwidth of the order of 90 MHz centred on the midband frequency (530 MHz) of the four London u.h.f. channels, Nos. 23, 26, 30 and 33. This corresponds to channel group "A". For other channel groups, slight alterations are necessary to the tuning.

When mounted adjacent to the set, an improvement in the noise figure of about 5 to 7 dB is possible, depending on the noise factor of the set's tuner, as we have already seen. Further improvement is possible with the amplifier mounted close to the aerial. The amplifier yields a gain of about 12 dB and consumes 2·6 mA at 9 volts.

The amplifier is required to operate from a 75 ohm aerial source but as, for optimum noise matching, the transistor should be presented with a source resistance of 50 ohms, a matching circuit is incorporated consisting of capacitor C1 and inductor L2. C1 is a concentric trimmer and L2 is the $\frac{3}{4}$ in. length of lead to C2.

Choke L1 protects the transistor from transient surges, such as lightning and incorrectly connected sets, while providing a bypass for unwanted low-frequency signals, the presence of which could cause intermodulation and interference troubles. Inductor L4 in conjunction with the output capacitance of the transistor, forms a circuit with a resonant frequency of 530 MHz. L4 has 2 turns over a 5 mm diameter of 22 s.w.g. enamelled copper wire. C3 is a small trimmer constructed of a piece of thin copper sheet 8 mm × 12 mm soldered to the collector lead of the transistor and arranged parallel to the centre screen.

Tuning is effected by altering the position of C3 and the turns spacing of L4. This method ensures that the bandwidth is less affected by tuning adjustments than if the coil alone were used for adjustment. The output signal is taken from a tapping on L4, via C4. The tapping is about one half-turn from the "earthy" end of the coil.

An emitter current of 2 mA is required from the 9 volt supply for the best noise and gain compromise. The bias is given by R1, R2 and R3, decoupled by the feedthrough capacitors C5, C6 and C7.

The emitter supply choke L3 and the protection choke L1 are made by winding 10 to 15 turns of 30 s.w.g. enamelled or cotton-covered wire round a rod of $\frac{1}{8}$ in. diameter, removing the coil from the rod and finally securing the turns together with polystyrene cement.

The chief extra requirement for the masthead version is that the power supply should be fed to the amplifier through the coaxial downlead. The circuit differences are small and are evident from an inspection of the two

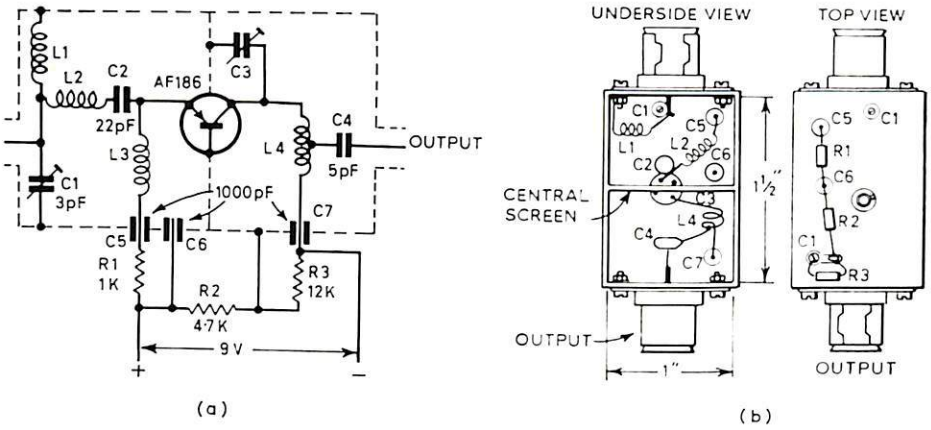


FIG. 6.4. *Circuit and constructional details of a battery-powered u.h.f. booster amplifier for set-side operation.*

circuits at Figs. 6.4 (*a*) and 6.5 (*a*). L5 in Fig. 6.5 (*a*) is a choke of similar construction to L1 and L3. The purpose of L5 is to provide a path for the negative d.c. supply without "shorting" the signal, bearing in mind that such a choke has a very low d.c. resistance and a very high reactance to u.h.f. signals. At the set end power is delivered to the downlead by a supply unit.

When mounted on an outdoor aerial, the amplifier should be provided with adequate protection from the weather.

The chassis is made from 18 s.w.g. brass sheet, with soldered joints, to the dimensions shown in Figs. 6.4 (*b*) and 6.5 (*b*). The most convenient way of mounting the transistor is to drill a piece of Paxolin or p.f.t.e. sheet to accommodate the transistor leads and mount the transistor in the round hole shown in Figs. 6.4 (*b*) and 6.5 (*b*), resting on the central screen. Note that C2 in Fig. 6.5 (*b*) is *not* a leadthrough type.

It is best to align any amplifier by means of a wobbulator, signal generator and oscilloscope (visual alignment), but when instruments of such specialized type are not available reasonable alignment is possible to give maximum gain on Channel 33 as follows:

Set C1 to about three-quarters of its maximum value (i.e., to about 2 to 2·25 pF). Connect the amplifier to the receiver with which it is to be used and temporarily insert a "through-type" u.h.f. attenuator in the aerial feeder to obtain a very grainy (noisy) picture. Adjust C3 and L4 to give the best picture with least noise.

MASTHEAD AMPLIFIER POWER UNITS

When the amplifier is used at the masthead, a supply unit must be used at the set end of the downlead, as already intimated. Such a supply unit is

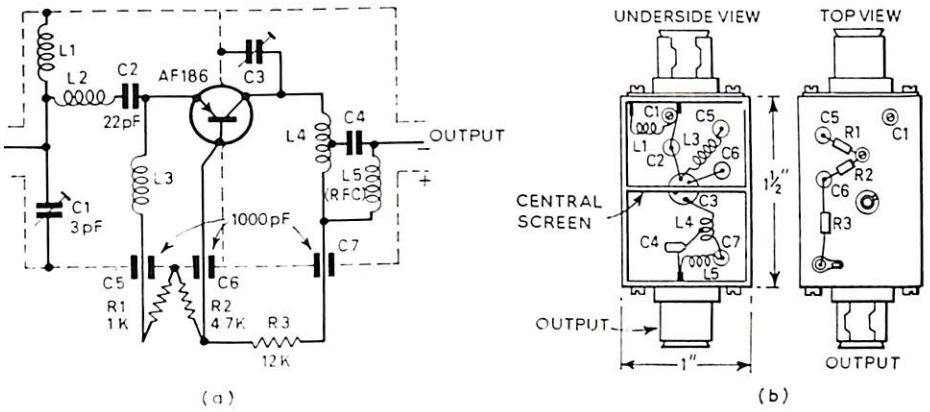


FIG. 6.5. *Circuit and constructional details of a masthead-mounted downlead-powered u.h.f. booster amplifier.*

shown in Fig. 6.6. The choke here is similar in design to L1, L3 and L5. It is best for the supply to be battery-driven, and on no account should it be connected to the mains power supply. The length of the supply unit, excluding the coaxial sockets, should not exceed $\frac{3}{4}$ in. As the amplifier consumes only 2 mA, a fairly large capacity 9 volt battery-pack will give months of service.

It is possible, however, to employ a specially designed mains power unit to run a masthead amplifier. There are several commercial units of this kind on the market. One of them uses a mains transformer the primary winding of which, instead of being connected directly across the mains supply, is connected in series with the mains supply to the television set. A special very-low resistance and impedance winding is used on the primary and this has virtually no effect on the mains input to the set. Thus, when the set is switched on in the ordinary way the mains power supply unit for the masthead amplifier is automatically powered.

The mains transformer can be really small as it is called upon to supply very little power for the transistor in the amplifier, and the secondary winding delivers little more than about 12 volts. Semiconductor rectifiers are used for these units and in the case of some models the output voltage is stabilized.

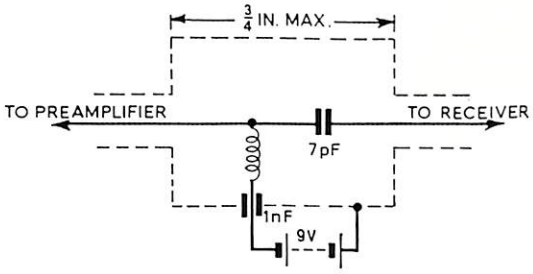


FIG. 6.6. *Circuit diagram of battery-power unit for the masthead u.h.f. booster amplifier given in* FIG. 6.5.

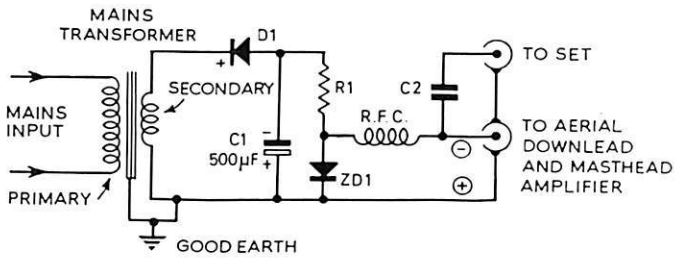


FIG. 6.7. *Circuit diagram of mains power unit for masthead amplifier.*

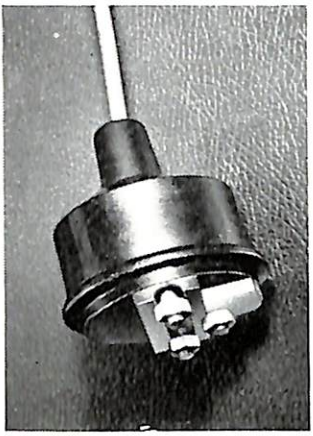
In Fig. 6.7 is given a circuit of a stabilized masthead amplifier mains power unit. Here the mains transformer can either have an ordinary mains primary winding (in which case an on/off switch may be included in the circuit) or a series winding, as already described. The secondary winding delivers about 12 volts r.m.s. and diode D1 rectifies the a.c. in the ordinary way. The reservoir electrolytic capacitor C1 charges and holds the d.c. voltage across it at a fairly constant value and clears the ripple.

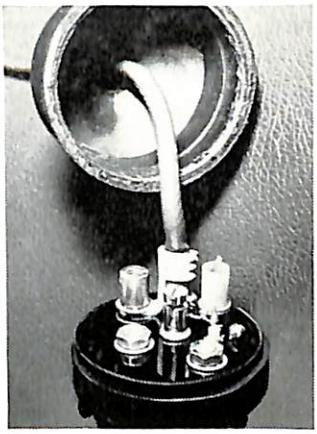
ZD1 is a zener diode which is operated in conjunction with the series resistor R1. The zener diode is biased in reverse conduction, and at a critical voltage, called the "zener voltage", the zener passes a relatively high current, called the "zener current". Now, the zener voltage remains substantially constant in spite of changes of current in R1, and it is this constant zener voltage that is used to feed the masthead amplifier.

The powering current flows through the r.f.c. (radio-frequency choke), which "holds off" the signal and thus avoids its attenuation, to the inner conductor of the aerial downlead going up to the masthead amplifier. The powering voltage on the inner conductor is negative and that on the outer conductor (braid) positive. For a masthead amplifier requiring reversed polarity (i.e., positive on the inner conductor and negative on the outer braid), D1, C1 and ZD1 should be reversed. Signal coming down from the masthead amplifier is "held off" by the r.f.c., as already explained, and is fed through C2 to the set. C2 passes the signals with little loss and blocks the powering d.c.

In the interests of safety, a good earth connection should be made to the core of the mains transformer and to the connection to the outer braids of the coaxial cables—also to the case housing the power supply unit if this is made of metal.

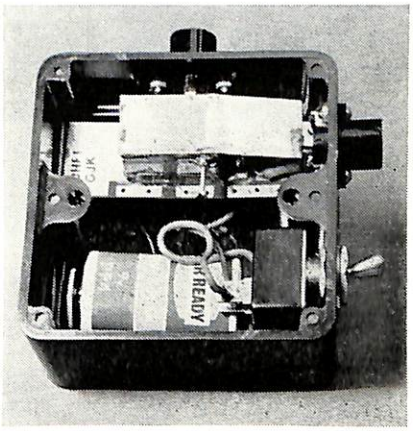
Fig. 6.8 shows a J-Beam balun case into which the author built an experimental Band III masthead amplifier. The terminals on the outside of this case connect direct to the dipole elements and power was fed to the amplifier from a mains power unit employing a circuit similar to that shown in Fig. 6.7.





(Left) FIG. 6.8. *Balun case into which the author built an experimental Band III amplifier.*
(Centre) FIG. 6.9. *The amplifier of* FIG. 6.8 *with the watertight cover removed.*
(Right) FIG. 6.10. *The reverse side of the amplifier assembly of* FIG. 6.9.

Fig. 6.9 shows the amplifier with the watertight cover removed. Here can be seen the Band III coil (tunable to the Band III channel or channels to match the aerial) and the terminations for the coaxial downlead. Fig. 6.10 shows the reverse side of the amplifier assembly, in which can be seen the various components and the transistor with the lead-out wire end facing upwards.



(Left) FIG. 6.11. *The King Telebooster, a dual-band amplifier designed for set-side use. (Transistor Devices Ltd.)* (Right) FIG. 6.12. *Inside view of the King U.H.F.-Telebooster.*

A dual-band v.h.f. set-side amplifier, called the King Telebooster, is shown in Fig. 6.11. This is made by Transistor Devices Ltd. in battery- and mains-powered versions.

The inside of the King U.H.F. Telebooster is shown in Fig. 6.12. This uses a special quarter-wave cavity-mounted tuning element instead of ordinary coils and is made in the set-side battery- and mains-powered versions and also as a masthead version.

As already mentioned, most aerial manufacturers now have some sort of transistor booster amplifier available, designed for their own particular aerial requirements. J-Beam Aerials Ltd., for instance, have evolved a u.h.f. masthead amplifier in their aerial balun case. The firm also supplies a zener-stabilized mains power unit to feed it with power. Belling & Lee Ltd. are pioneers of transistor amplifier design, having designed a v.h.f. version for use in communal and coaxial relay systems and subsequently u.h.f. models. Teleng Ltd., the relay firm, is another pioneer in the field, and others include Labgear Ltd. and Rainbow.

A single-stage, well-designed transistor amplifier can yield a voltage gain up to 18 dB or so on a single Band I or Band III television channel and 15 dB or so over the whole of Band II. The gain over about 100 MHz is somewhat less on the u.h.f. bands, but usually ranges from a maximum of 14 dB down to about 9 dB—or less on the top Band V channels. The noise figure should not fall too much below 5·5 dB on all except, perhaps, the top Band V channels.

Care should be taken when using an aerial with a booster amplifier in circuit close to a television or v.h.f. f.m. radio set, for the extra gain given by the amplified aerial system can lead to instability and signal radiation due to feedback from the final i.f. stages of the set back to the aerial. The effect can happen without an amplifier when the aerial is very close to some sets, but it is aggravated by the additional gain provided by the booster.

CHAPTER 7

Shared Aerial Systems

A SHARED aerial, as its name implies, is a system whereby the received signals can be shared by a number of receivers, radio and television. A well-designed system can feed tens, hundreds or indeed thousands of receivers from its one set of master aerials. These aerials are of more robust construction than those used individually by viewers and listeners, and they are sited on high land, where possible, close to the area to be served.

Since the cost of the aerials and the installation is effectively shared among the owners of the connected receivers, a very efficient aerial system can be employed, located with regard to signal field and interference. From first principles, therefore, a shared aerial system consists of the master aerials and cables connecting these with the households of subscribers to the system. The basic idea is shown in Fig. 7.1.

A shared aerial system satisfies two major requirements. It brings to a household screened by large buildings, hills, etc., v.h.f. signals of a quality and strength which could only be obtained otherwise on high ground on the fringe of the area, and it avoids each household having to erect large

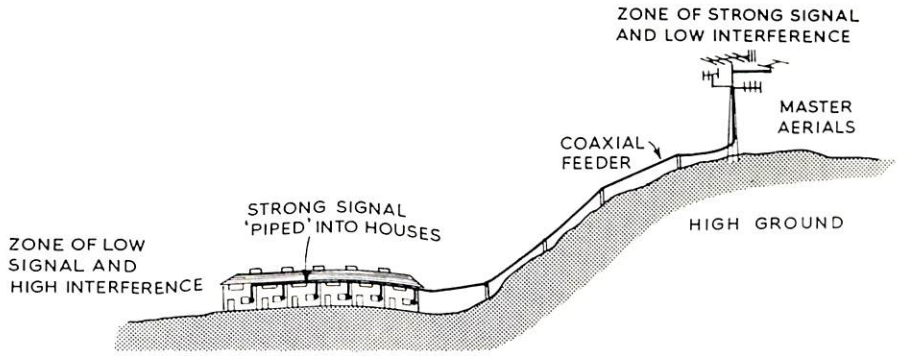


FIG. 7.1. *A shared aerial system is designed to "pipe" strong, interference-free signals from a master aerial mounted on a high site to a number of houses badly served with local signal due to screening and high interference. The signals are fed through coaxial transmission line.*

separate aerials for each channel or band in an endeavour to receive signals of more than mediocre strength and interference ratio.

At the time of writing, one household may have to use four multi-element arrays in an area of poor signal strength and high interference to get the best possible signals from BBC1, BBC2, ITV1 and the f.m. radio service. On the shared chimney-stack of a semi-detached house this represents a potential of eight separate aerials! In practice this is an impossible number, and some of the arrays have to be fixed to the walls of the building or on poles in the garden—not a very pleasant sight when multiplied many times.

The shared aerial combats these problems, and estate controllers, builders and local authorities are fast becoming aware of the desirability of shared aerial systems relative to their own interests. Large, heavy arrays on the stack of a chimney must also be considered a hazard in high winds and stormy weather.

The first shared aerial systems were erected mainly in areas of poor signal field and high interference, by both private concerns and local authorities, to give subscribers reception considerably better than that possible by the use of individual aerials. Systems ranged in size from blocks of flats to small and large housing estates and to whole towns.

The trend is now to plan shared systems less from the signal aspect, since the majority of areas in Great Britain are placed in quite usable signal fields, and more from the amenity aspect, to clear the skyline of the diversity of "rods and perches", which signified the advent of the television era.

Shared aerial systems, as such, are confined essentially to blocks of flats, groups of houses and housing estates, rather than large towns and cities. For large-scale signal distribution a more sophisticated method is adopted, whereby the system embraces also the receivers.

COAXIAL SYSTEM

Shared aerial systems use coaxial transmission line for connecting the aerials to the receivers, and the signals are distributed within the v.h.f. bands, either at frequencies corresponding to their natural channel numbers or at frequencies corresponding to more convenient channel numbers, but still within the "standard" v.h.f. bands.

With this kind of system, therefore, any "standard" domestic television set or v.h.f. f.m. radio can be utilized. Indeed, the signals are "piped" into the house from the master aerials in rather the same way as gas, water, electricity and telephones. In the subscriber's living room one or two coaxial outlet sockets deliver the signals to the television receiver or to the television receiver *and* the v.h.f. f.m. receiver. All the signals, however, are carried in a single coaxial cable.

At the master aerial site the u.h.f. signals are received in the usual way,

but they are "translated" to a frequency corresponding to an unused v.h.f. channel (in Band I or III). Thus, *all* signals are distributed at v.h.f. Frequency translation of the u.h.f. signals is necessary owing to the high losses which would be encountered in the distribution cables by attempting their "piping" at natural frequency. Only in very small networks, such as used in dealers' shops, in small blocks of flats, and between next-door neighbours, is it feasible to distribute at frequencies corresponding to channels in Bands IV and V, but this could alter in the future.

U.h.f. translation to v.h.f. channels gives rise to a little complication at the receiver when dual-standard receivers are employed. A dual-standard set has two aerial input sockets, one for v.h.f. signals in Bands I and III and the other for the u.h.f. signals in Bands IV and V. Such sets feature either two tuners or an "all-band" integrated tuner. Thus, when a set of this kind is connected to a shared aerial system the u.h.f. tuner is redundant. This is of no consequence, for it is a simple matter not to use it, and it can prove an economy since most dual-standard sets can be purchased at a lower cost with the v.h.f. tuner alone.

The main problem arises from the fact that the set is switched to the 625-line standard only when the u.h.f. tuner is in circuit. With the v.h.f. tuner in circuit, as is required for shared aerial systems, the set is automatically switched to the 405-line standard.

It is thus necessary to rearrange the set so that on the selected v.h.f. channels carrying the translated u.h.f. signals the set is switched to the 625-line standard. There are various ways of handling this problem, and most dual-standard sets have easy facility for changing to the shared aerial mode of 625-line operation. Receiver manufacturers have realized this problem and designed their sets accordingly.

Not all channels in Bands I and III are occupied on a shared aerial system because it is generally desirable to have a "guard" channel between channels distributed to satisfy certain limitations of the receivers with regard mainly to adjacent channel performance. If two powerful signals on adjacent channels are applied to a set, it is often difficult completely to eliminate the sound carrier of one breaking into the vision carrier of the other, causing 1·5 MHz diagonal interference lines on a 405-line picture.

There are plenty of channels available in Bands I and III, so the need for so-called guard channels is not very important. Some shared aerial systems distribute BBC1, BBC2, two ITV programmes and the Radios 2, 3 and 4 v.h.f. f.m. programmes. Of course, either a television set with f.m. radio facilities or a separate f.m. set is necessary to receive the f.m. signals distributed. Up to four 405-line channels and three 625-line channels can be accommodated in Band I and four (probably more) 625-line channels in Band III. The f.m. programmes are always distributed at their natural

frequencies, but it is possible to introduce an additional sound programme within Band II. This is achieved by frequency-modulating the required programme on a v.h.f. channel in Band II.

For instance, some shared aerial systems distribute Radio Luxembourg. This is done by receiving the programme on an ordinary a.m. radio or tuner, and then frequency-modulating the audio on to a v.h.f. carrier produced by a special carrier-generator/modulator. The resulting f.m. output is then combined to the main feeder cables.

Table 7.1 gives the recognized v.h.f. channels for the 625-line standard as applicable to shared aerial systems.

Distribution systems employing coaxial cable and utilizing v.h.f. signals, making them suitable for use with ordinary receivers, are called either "coaxial systems" or "v.h.f. systems". They are popular with radio and television dealers and with local authorities since they do not inhibit the use of ordinary sets. Thus, a viewer moving into an estate with such a system can continue employing his original set, while a viewer moving out of such an estate back to ordinary aerials need not purchase a different set.

MULTI-WIRE SYSTEM

The other type of system which is sometimes considered to be more suitable for large towns and cities does not make extensive use of coaxial transmission line (feeder), but instead employs a multiple-conductor type of cable, with two conductors (acting as balanced twin cable) for each television channel distributed. Here the vision signals are translated to quite low frequencies, sometimes below 10 MHz, while the sound signals may be distributed at audio frequency at sufficient power to operate subscribers' loudspeakers direct.

This technique certainly simplifies the receiving equipment at each outlet, and the low signal frequencies reduce the cable losses, thereby making amplification on the network less severe, compared with coaxial systems.

Table 7.1

V.H.F. CHANNELS FOR 625-LINE STANDARD

Channel	*Vision (MHz)*	*Sound (MHz)*
A	45·75	51·75
B	53·75	59·75
C	61·75	67·75
D	175·25	181·25
E	183·25	189·25
F	191·25	197·25
G	199·25	205·25
H	207·25	213·25
I	215·25	221·25

However, very large audio power amplifiers are needed to feed adequate power to each connected loudspeaker and the system as it stands is totally unsuitable for working ordinary sets.

The large multi-wire "relay" firms, though, have attempted to combat this disadvantage by designing so-called inverters which, when connected between the system and ordinary television sets, permit their use. These devices effectively translate the low carrier frequencies back again to v.h.f. channels acceptable by ordinary sets. Of course, best results are obtained on the special type of receivers designed for the system. These are usually called "terminal units" and are rented along with the use of the system by the relay company.

As multi-cable relay systems (also called h.f. systems) are not truly shared aerial systems they will not be considered further. All of the following, therefore, relates to systems employing a single coaxial cable as distinct from multi-conductors. Within a single coaxial cable can be "locked" a complete radio and television spectrum, and it is this feature that gives the system many of its advantages.

Ordinarily, as has been said, the signals carried by the cable correspond to channels in Bands I, II, III, IV and V, but there is no reason why signals below Band I could not be distributed along with the "standard" frequency signals. The basic sound and vision entertainment signals occupy only a portion of the available "radio space" present in a good-quality coaxial cable, leaving plenty of room for such things as pay-television, local a.m. radio programmes, control pulses, power for working the repeater amplifiers and so forth.

Any number of separate signals can be launched into a single coaxial cable and the cable, being essentially linear, will carry each of them in complete isolation. The signals will emerge from the far end of the cable and they can then be processed as required.

START OF SYSTEM

Fig. 7.2 shows how f.m. radio and television signals are launched into a cable system. If necessary, the signals at each aerial are lifted in level by masthead amplifiers to provide the best signal/noise ratio which is considerably important at the start of any system.

It may be found that the aerial signals direct are sufficiently strong to avoid masthead amplification, and small systems may only have one or two masthead amplifiers, for the Band III channel and the u.h.f. channel. It is desirable, however, always to employ a good, low-noise masthead for the u.h.f. channel. The idea is to raise the aerial signals on the vision carrier to about 3 mV or, at least, to 1 mV if this is possible. The sound signals are then usually of the order of 1 mV, as also are the v.h.f. f.m. Band II signals.

The best possible type of aerial for each channel consistent with the nature of the system should always be employed, for the start of the shared aerial system is always the most important and there is virtually nothing that can be done subsequently to counter poor aerials and poor signal/noise performance at the first amplifiers. The aerials should be erected as high as possible and as close as possible to the area of distribution. The choice of aerial should be governed by the local conditions with respect to signal strength, interference of all kinds, fading and multipath distortion (i.e., signal reflections from hills, large buildings, aircraft and so forth).

It is usually possible to employ aerials of more elaborate proportions than would be economically feasible for a private system feeding just one receiver. The greater height of the master aerials also means that they will be subjected to winds of greater strength than their household counterparts.

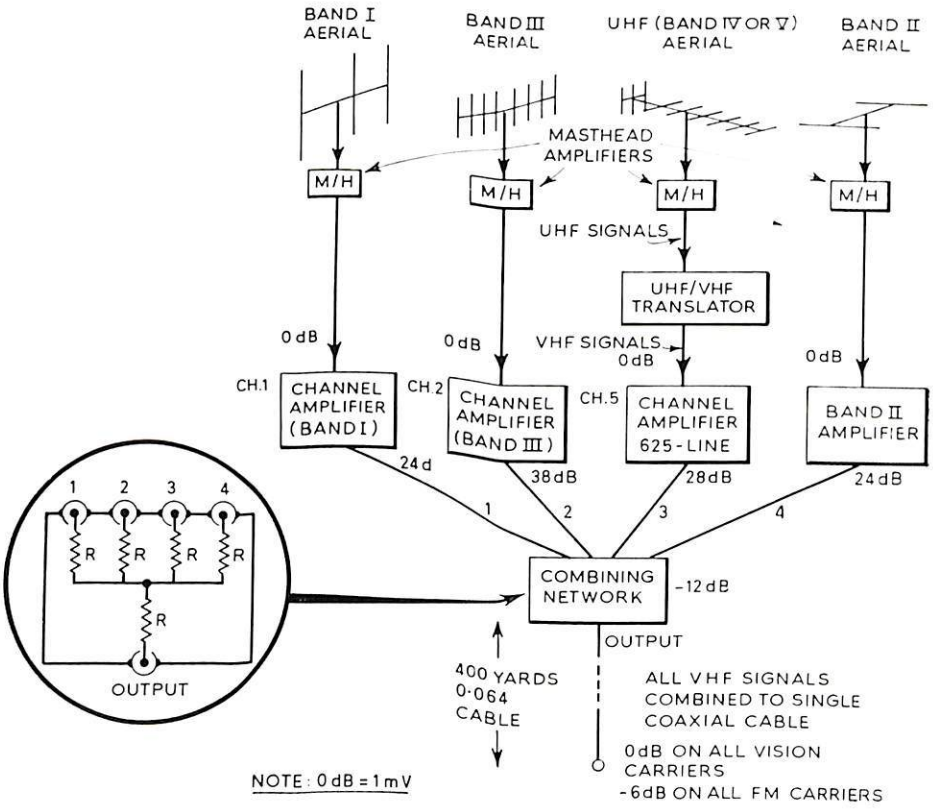


FIG. 7.2. *The start of a shared aerial system. This is fully explained in the text. Note that a tuned filter may be used for combining the signal instead of the resistive network shown encircled.*

FIG. 7.3. *A complex Band III master aerial.* (*Belling & Lee Ltd.*)

Firms specializing in shared aerial equipment market "ruggedized" aerials well able to withstand wind velocities associated with high-altitude sites.

Sometimes rather elaborate arrays are demanded to get as much as possible of a very weak signal from a distant station, and Fig. 7.3 shows a specially designed array of Band III Belling & Lee aerials at the top of a mast related to a Belling & Lee coaxial system. The top of the master aerial mast of a system using Teleng equipment is shown in Fig. 7.4.

Referring again to Fig. 7.2, the signal from each v.h.f. aerial (via its own masthead amplifier) is applied to the input of an amplifier tuned to the specific channel being distributed. The signal from the u.h.f. aerial is first fed

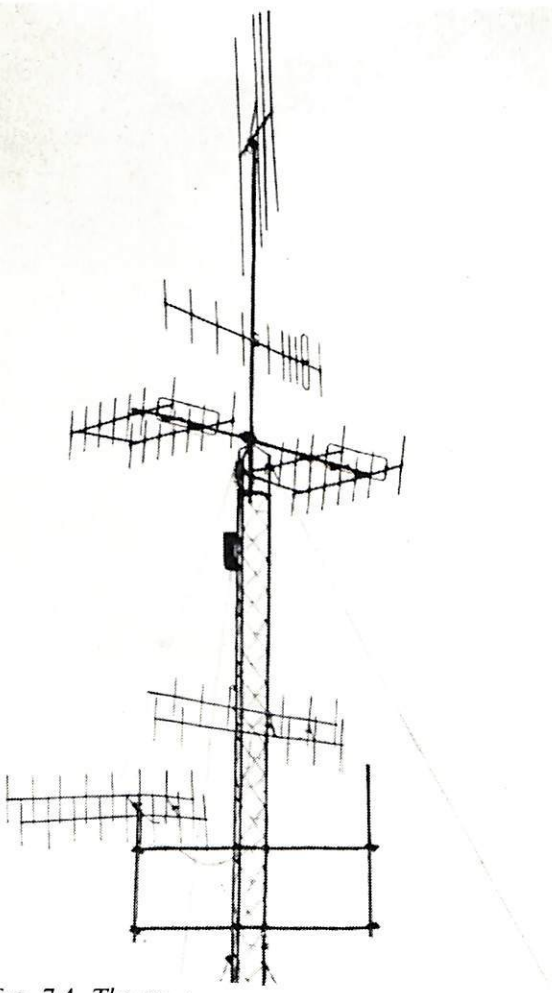
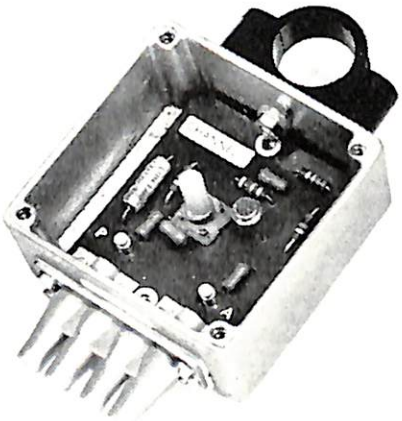
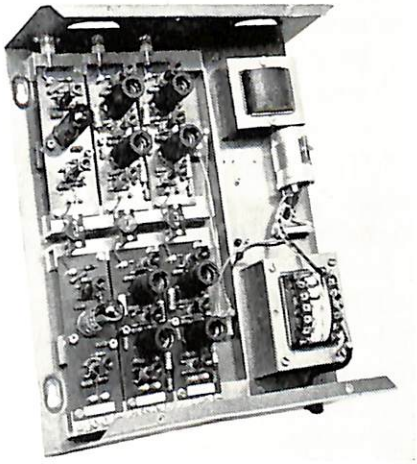


FIG. 7.4. *The master aerial of a coaxial system.*





(Left) FIG. 7.5. *Masthead v.h.f. amplifier using a transistor.* (*Belling & Lee Ltd.*)
(Right) FIG. 7.6. *A bank of distribution channel amplifiers. This has a unit adjacent for mains powering.* (*Belling & Lee Ltd.*)

to the u.h.f./v.h.f. translator to convert it to a suitable v.h.f. channel in Band I or III and thence to its own channel amplifier.

Fig. 7.5 shows a transistorized masthead amplifier by Belling & Lee. This type of equipment is available for Band II and channels in Bands I and III, in medium and high gain versions, nominally 14 dB and 22 dB respectively. A smaller version is also available for the u.h.f. channels and bands with gains of the order of 25 dB, depending on type.

Fig. 7.6 shows a bank of Belling & Lee "channel" amplifiers as could be used in Fig. 7.2. Various combinations of the two-valve amplifier "blocks" can be derived, as required. Each block has a gain of about 25 dB and two blocks per channel (giving three channels as shown) can be cascaded giving an overall gain per channel of 50 dB.

On larger systems it is a good idea to have a gain control at each channel amplifier so that the signal levels at the output of each channel amplifier can be adjusted to suit the run of cable and its differential losses up to the outlets.

SIGNAL LEVELS

To ensure that the sets connected to the system operate well the level of the vision signals on each channel should not be much below 1 mV and the sound signals 0·5 mV at each outlet. On a well-designed system, these design levels should be maintained over the whole distribution network within about ± 3 dB. This is not particularly easy to achieve because the

signals of the various channels are not equally attenuated with distance along the cable. In earlier chapters it has been shown that the higher-frequency signals are subjected to greater attenuation than the lower-frequency ones. Moreover, the items of the network contribute to the total attenuation from the start to the outlets of a system.

The combining network of Fig. 7.2, for instance, itself attenuates the signals. This attenuation is the price that has to be paid for correct matching to the various cable systems. It is not possible, as we have seen, simply to connect signal cables in parallel. A matching network is essential to avoid standing-wave conditions that can seriously detract from the efficiency of a shared aerial system; but standing waves can also result in signal radiation from the cable networks and interfere with receivers taking their signals from ordinary, private aerials. The Post Office keeps a very watchful eye on shared aerial systems for possible cable radiation and resulting interference.

A resistive combining network of the nature shown in Fig. 7.2 would tend to attenuate the signals from the channel amplifiers by as much as 12 dB. In practice, this loss is reduced by the employment of more specialized units, some using ferrite-cored inductors. For the sake of description, let us suppose that the four-way combining filter in Fig. 7.2 has a 12 dB loss—"insertion loss", as it is called. Let us further suppose that we are lucky and that each channel amplifier is receiving a signal of 1 mV from the aerials, via the mast-head amplifiers, and that we require a signal of 1 mV on all vision carriers at the end of, say, a 400-yard length of coaxial cable.

CALCULATING GAIN

The best plan is to work in decibels, forgetting for the time being signal levels in terms of voltage. In shared aerial parlance, a signal level of 1 mV is referred to as 0 dB. Thus, the signal level at each channel amplifier is 0 dB. The signal level at the outputs will, of course, depend on the voltage gain of the amplifiers.

The signal attenuation over 400 yards of low-loss cable of the kind used in distribution systems depends very much on the diameter of the inner conductor, on the nature of the dielectric, and on the signal frequency. For instance, cable with an 0·064 in. inner conductor and high-grade Polythene extruded air cell dielectric has an attenuation per 100 yards of 3 dB at 40 MHz, 3·9 dB at 70 MHz, 4·5 dB at 100 MHz and 6·3 dB at 200 MHz.

Based on cable of this type, our 400-yard length would have an attenuation of 12 dB at Channel 1, 18 dB at Band II and 26 dB at Channel 10. If the u.h.f. signal is converted to, say, Channel 5, then at that frequency the attenuation would be about 16 dB. There is no need to calculate to tenths of a decibel over this length of cable.

We can now discover just how much gain the channel amplifiers will

need to give 0 dB of vision signal at each outlet. The Band I amplifier would need a gain of 12 dB *plus* the 12 dB combining filter loss, that is 24 dB, the Band III amplifier 38 dB, the 625-line v.h.f. amplifier (working on Channel 5) 28 dB, and the Band II amplifier 30 dB — 6 dB, or 24 dB (the minus 6 dB is because only half the signal level is required for sound signals generally). The sound signals accompanying the vision signals will automatically be less than 0 dB, often around −6 dB, or 0·5 mV.

Note that in all the calculations, the 12 dB loss of the combining filter has been taken into account.

The signal levels become important in terms of signal voltages when it is required to know whether the amplifiers are capable of delivering the necessary signal voltages before running into conditions of overload. Most channel and distribution amplifiers can deliver 100 mV or more of peak white vision signal before arriving at the fringe of overload. This means, then, that a gain of 40 dB (100 times voltage ratio) can be accommodated when the input signal is 0 dB (i.e., 1 mV). At 40 dB, the output is then 100 mV.

It will be instructive to consider the signal levels in terms of voltage at the output of the amplifiers in Fig. 7.2. Relative to 1 mV equals 0 dB, we thus have 24 dB on Channel 1, or 15·85 mV; 38 dB on Channel 10, or 79·43 mV; 28 dB on Channel 5, or 25·12 mV; and 24 dB on Band II, or 15·85 mV. All these levels are well within the overload characteristics of most amplifiers.

The signals applied to the cable will all be 12 dB (four times) *below* these signal voltages owing to the attenuation of the combining filter.

The signals would be measured on a signal strength meter calibrated either in signal voltage or in decibels, with 0 dB equal to 1 mV or 0·5 mV, depending on the nature of the instrument. The gain controls of the channel amplifiers would be set roughly and then a check would be made at the signal outlet socket at the far end of the cable. If necessary, slight readjustment to the controls would be made to equalize all the vision signals.

DOUBLE-SCREENED CABLE

It is obvious that substantial signal voltages are present in the cable, and if this is routed along houses, as it usually is, slight signal radiation from it can upset the reception of viewers using their own aerials. To guard against this sort of radiation, cables for shared aerial systems often have two outer screens, as shown in Fig. 7.7.

The cable comes in various sizes, and the size is often identified in terms of diameter of the inner conductor; the larger the diameter, the less the attenuation (and, of course, the greater the outside diameter of the cable proper). For really low-loss trunk circuits the inner conductor may be as large as 0·104 in. Other sizes in general use are 0·064 in., 0·048 in. and 0·022

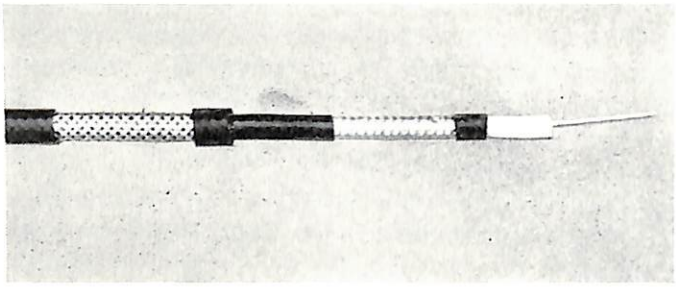


FIG. 7.7. *Double-screened coaxial cable. The double screening reduces signal radiation from the cable and thus greatly minimizes interference in areas of low "off-air" signal when the cable signal level is high.*

in. These have overall outer diameters of 0·652 in., 0·425 in., 0·380 in. and 0·260 in., and attenuation figures per 100 ft at 100 MHz of 1·1 dB, 1·5 dB, 2·1 dB and 4·3 dB respectively. The latter type of cable, which is relatively thin, would be used as a downlead connecting a subscriber.

Instead of using two braid-type outer screens some of the latest shared aerial cables are made with a solid metal outer conductor in the form of a tube. This may be made of copper tape, and to provide some degree of flexibility and to avoid kinking when bending, the tape is corrugated axially. Such cables have a very small signal leakage co-efficient.

There are not many instances where a set-up such as that shown in Fig. 7.2 would be used to supply just one receiver. Usually, the main coaxial feed cable (often called the "trunk cable") would feed a number of receivers in a block of flats, block of terrace houses or housing estate.

RECEIVER TAKE-OFFS

Thus, the signal cannot be extracted direct from the cable, for it is not possible to parallel receivers to a common cable as has already been observed. One way of extracting a subscriber's signal from the cable without introducing mismatch conditions of any magnitude is by the use of a take-off resistor, as shown in Fig. 7.8. The parallel resistor across the subscriber's downlead is not always used. Its purpose is to "match" the top of the cable so as to reflect the correct value of impedance at the receiver input, and it may be used only when standing waves on the downlead are troublesome, depending on how well the set itself loads the cable at the other end.

The attenuation from the main cable to the subscriber's cable is, of course, governed by the value of the take-off resistor—the greater the value the greater the attenuation. The attenuation in decibels is given by the expression:

$$20 \log_{10} \frac{Z + Rh}{Z}$$

where Z is the impedance of the cable at its point of connection to the take-off resistor Rh. When a parallel resistor is used at the top of the downlead, the attenuation value is increased by approximately 3 dB over that given by the foregoing expression.

When signal is taken from a cable, the cable is loaded and its attenuation rises in approximation to the expression:

$$20 \log_{10} \frac{Z + Rh + \left(\frac{Zm}{2}\right)}{Z + Rh}$$

where Zm is the impedance of the main cable at the point of connection to the take-off resistor Rh and Z is the impedance of the subscriber's cable.

As typical examples, a 24 dB tee-loss produces a rise in main cable attenuation of about 0·5 dB, while 10 dB tee-loss produces a rise of about 1·3 dB in main cable attenuation. Thus, the greater the tee-attenuation, the smaller the main cable attenuation. Clearly, as a large number of subscribers are connected, so the main cable loss rises well above its virgin (unloaded) value.

There are various designs of take-off boxes employing the take-off resistor technique for subscribers. An interesting arrangement is shown in Fig. 7.9. Here the take-off resistor is spring-loaded in the metal housing and one end is connected to the inner conductor of the subscriber's downlead. The wire end shown protruding through an aperture is cut short. A hole is drilled in the main cable with a special tool which exposes both the inner conductor and the outer braid. The short wire end of the resistor presses hard

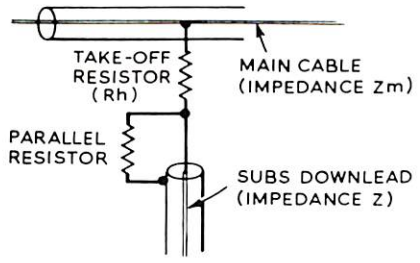


FIG. 7.8. *Simple resistive type of subscriber's signal take-off. The parallel resistor is not always used.*

(Right) FIG. 7.9. *Cable-clamp type of subscriber's take-off. This type of take-off is also made with a ferrite transformer.*

against the inner conductor, while the rising edge round the aperture presses hard against the braid. The device is clamped against the cable, and the two connections are soundly made to the downlead. The tight clamping avoids the ingress of moisture.

Incidentally, the cable shown in the picture is of a special type with a built-on catenary wire for supporting it across overhead routes.

It is desirable—and, indeed, a Post office recommendation—that the attenuation from a subscriber's downlead back to the line is not less than about 20 dB. With the resistive type of take-off, the back attenuation is the same as the forward attenuation, which means that take-offs with a tee-attenuation less than 20 dB should not normally be used.

SIGNAL AND ELECTRICAL ISOLATION

Signal isolation back to line from a downlead should be kept as high as possible, to reduce the main line attenuation and to prevent high-level interfering signals that may be generated at the aerial socket of a connected receiver from getting into the main line and affecting the reception of other subscribers. On small systems an isolation value less than 20 dB can sometimes be tolerated, and for this purpose take-offs with a tee-attenuation less than 20 dB are available.

There are also directional-coupler type take-offs which have a relatively low line-to-subscriber attenuation and a higher reverse subscriber-to-line attenuation. Other types employ a ferrite-cored transformer and loading resistor in place of the ordinary take-off resistor. These transformers are similar in technique to the wideband transformers employed in certain wideband v.h.f. amplifiers and signal splitters.

It is also a ruling that each connected receiver to a shared aerial system should be electrically isolated from the network. With certain transformer take-offs such isolation is automatic. However, with hybrid and resistive take-offs isolation is achieved by suitable capacitors at the outlet sockets. Capacitors are generally connected in series with both the inner and outer conductors so as to prevent the network and other connected receivers from damage in the event of the mains isolation in a receiver failing, a fault that could otherwise put mains potential on the network and on other outlets.

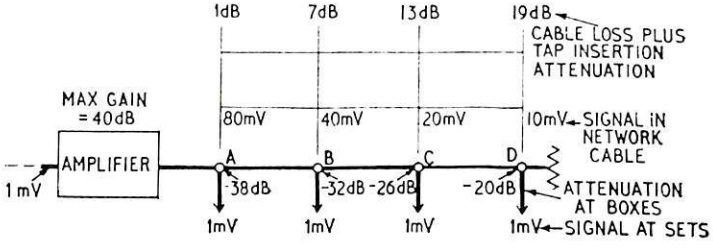
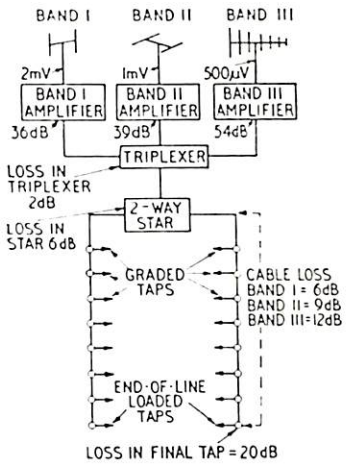
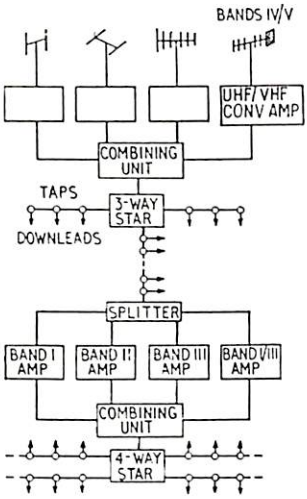


FIG. 7.10. *Showing the signal levels along a main cable connected to take-offs.*





(Left) FIG. 7.11. *Typical three-band shared aerial system. This is fully explained in the text.* (Right) FIG. 7.12. *A more complex system with a u.h.f. channel added.*

Isolating capacitors should have a working rating of at least 240 volts a.c. and their value should not exceed 0·005 μF. A higher value would have a sufficiently low reactance at 50 Hz mains frequency to inject too high a mains current in the event of a receiver fault.

Clearly, then, channel or distribution amplifiers must have sufficient gain to counter the tee-attenuation of subscriber take-offs as well as the attenuation of the cable itself (bearing in mind that when loaded to take-offs it is higher than when unloaded) and any other network, such as signal splitters and combiners.

SYSTEM TECHNIQUES

Fig. 7.10 shows how the signal at a given frequency from an amplifier is progressively attenuated along the cable, the loss being made of both cable and take-off attenuation (total) 18 dB. This shows how 0 dB (1 mV) of down-lead signal can be maintained at take-offs A, B, C and D by the use of values of 38 dB, 32 dB, 26 dB and 20 dB respectively. In practice, assuming no additional losses, the amplifier would have a gain of 40 dB and adjusted to give an output of 80 mV to apply to the start of the network.

The ends of cables must be loaded with non-inductive resistors of value equal to their characteristic impedance. Such loading is necessary to avoid standing waves and consequent unpredictable signal levels along the cable.

A typical shared aerial system is shown in Fig. 7.11. To assess the amplifier gains it is necessary first to calculate the total loss of the system at all the frequencies used. Components other than the cable will generally

have a constant attenuation, irrespective of frequency, so it is best to discover the total of these losses first, working back from the final take-off.

The final take-off has a loss of 20 dB, the two-way "star" network 6 dB, the triplexer 2 dB and the eight take-offs in each leg total 8 dB insertion loss, giving a total of −36 dB.

At Band I the cable has 6 dB attenuation which, added to the 36 dB, gives a total of −42 dB. We require to design for 0 dB at each outlet, but if the Band I amplifier be set for a gain of 42 dB (to exactly cancel the loss) each outlet would deliver 6 dB (or 2 mV), equal to the aerial signal level. It is thus necessary to halve the aerial signal, which is the same as taking 6 dB from the gain of the amplifier. This works out to 36 dB, which is the gain to which the Band I amplifier should be adjusted.

On Band II, the cable attenuation is up to 9 dB. Added to the other fixed losses, this gives a total of 45 dB. The aerial signal is 1 mV here (0 dB), and as we need only 0·5 mV of sound signal at each outlet, the gain of the Band II amplifier should be set to 39 dB, that is, 45-6 dB.

On Band III, the cable attenuation is 12 dB. Added to the fixed losses, this gives 48 dB. As there is only 0·5 mV of aerial signal on this channel, 6 dB of gain must be *added* to give 0 dB at each outlet. Thus, we have 48 +6 dB, totalling 54 dB, being the gain required by the Band III amplifier.

Subscribers' take-offs must be graded upwards from −20 dB at the final to −38 dB at the start where the signal levels are highest.

Systems can be extended by splitting the network and adding channel repeater amplifiers as shown in Fig. 7.12. This also shows the addition of a u.h.f. channel.

Splitters and combining units can be of the nature of the various networks detailed in Chapter 5 or they can be tuned or inductive networks usually giving a smaller insertion loss than the resistive devices. However, the bandwidth of the various networks must be taken into account when designing a multiple-channel so-called wideband system, embracing Bands I, II and III.

To avoid splitting the signals for separate amplification, as shown in Fig. 7.12, wideband repeater amplifiers are available. These have bandwidths from 30 MHz or below, up to 225 MHz or higher, and are designed to handling a multiplicity of sound and vision carriers at high level (50 mV or more). Some such repeaters have an output in excess of 1 volt on a single carrier. Of course, when a number of carriers are handled, the maximum output voltage per carrier is decreased.

Wideband amplifiers often use valves arranged in a "distributed" circuit, whereby the valves are not cascaded but arranged so that their effective slopes add, giving a very high overall figure of merit (i.e., gain/bandwidth factor). An advantage of this kind of amplifier in shared aerial systems is

that should one valve fail the amplifier continues working at slightly reduced gain. An amplifier of this kind, the Teleng U180, is shown in Fig. 7.13. This uses twelve EF95 valves which give a gain of 20 dB nominal over the range 40 to 220 MHz. The full output on one carrier is 1 volt.

Transistors are also featured in shared aerial repeater amplifiers, a particular example being depicted in Fig. 7.14. This is an amplifier from the Thorn range of equipment, and the picture shows how neatly it can be mounted on a wall, beneath a roof. The smaller unit at one end is a splitter that gives outputs for feeding two cable systems.

The larger type of valved repeated amplifier is usually mains-powered direct, while smaller units can be powered over the coaxial network. A low-voltage a.c. is passed into the network through power-pass filters (which are isolated from the signals) and at the repeater system a similar power-pass filter extracts the power and guides it into the power supply circuits, again without affecting the signal circuits. The technique adopted is similar to that described in Chapter 6 for the cable powering of masthead amplifiers (see Figs. 6.6 and 6.7).

The smaller power requirements of transistor repeaters facilitate line powering and d.c. voltage instead of a.c. is often fed through the cable to the repeaters.

Systems of extended networks and cascaded repeater amplifiers demand automatic gain control systems at intervals along an extended cable run. There may be three or four repeaters and then a repeater with automatic gain control (a.g.c.) facilities, then three or four more repeaters and so on.

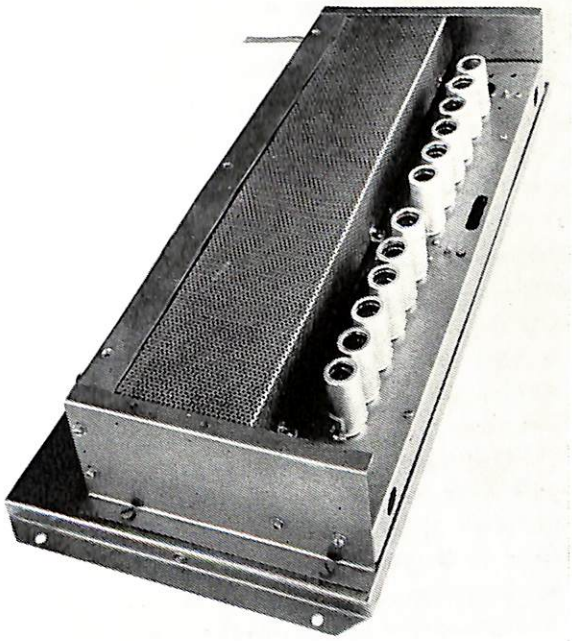


FIG. 7.13. *Wideband repeater amplifier.* (*Teleng Ltd.*)

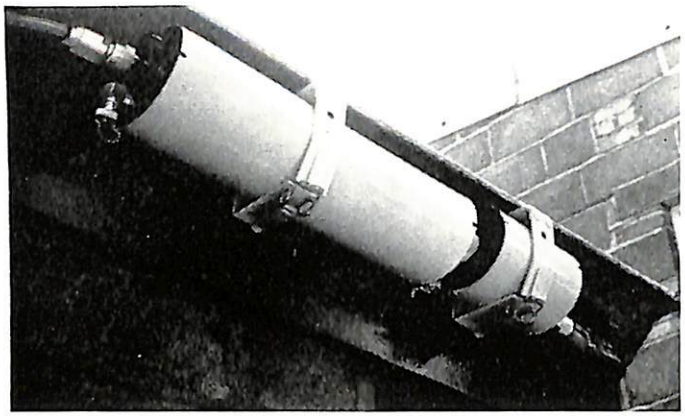


FIG. 7.14. *Transistor wideband repeater amplifier mounted on a wall, beneath a roof. The small unit attached is a two-outlet splitter.* (*Thorn Electronics Ltd.*)

AUTOMATIC GAIN CONTROL

Although the need for a.g.c. is obvious at aerial amplifiers to iron out signal fades, the reasons for incorporation of a.g.c. in the network itself are firstly to correct the signal levels at pre-selected intervals, since these can rise and fall considerably with extremes of temperature (for instance, the attenuation over a mile of cable can change by as much as 20 dB between summer and winter) and secondly to break down the repeater network so as to permit the correction of signal levels on each carrier.

Some a.g.c. systems filter out the various channels on the system and allow their levels to be individually corrected to avoid the overloading and progressive unbalance of signals in subsequent networks and repeater amplifiers.

The a.g.c. function is controlled either direct by signal level on the cable system or relative to the level of a "pilot carrier" piped over the cables along with the programme signals. If the signal level as "seen" by the a.g.c. system falls, then the gain of the amplifier rises and thus compensates for the signal decrease. On larger systems, too, equalization is necessary because the increase in attenuation with increase in frequency is considerably aggravated over extended tracks of cable.

One method for introducing equalization in a system consists of a network unit whose attentuation decreases with increase in frequency, the characteristic opposite to that of the cable. These units are interposed at intervals in the cable network to provide an overall characteristic that is less frequency selective. Another method equalizes at the repeater amplifiers themselves. The responses of the repeaters are arranged to rise from the low-

frequency end to the high-frequency end, the slope being adjusted to balance the opposite slope of the cable.

It is, of course, impossible to detail large shared aerial systems in the compass of this chapter, and readers needing more information on the subject are referred to the author's book *Communal Aerials and Coaxial Relay Practice*, published by the author at Brixham, Devon, price 8s. 6d.

FAULTS IN SHARED AERIAL SYSTEMS

On a properly engineered system the main trouble will be unbalance of signal levels. This can give rise to a host of symptoms as detailed below.

Poor Signal/Noise Ratio. This is revealed by excessive grain on the pictures and probably undue noise on sound. The trouble is mostly caused by a poor signal/noise ratio at the start of the system. A weak aerial signal, especially on a u.h.f. channel and as fed to a u.h.f./v.h.f. translator, is the most frequent cause of the fault, and in this respect the only solution lies in increasing the signal either by re-orientating or re-siting the aerial or by the use of an aerial of greater gain and directivity.

When one is satisfied that everything has been done to capture as much signal as possible by the aerial, attention can be given to masthead amplification. If such an amplifier is not employed on the channel or channels affected by noise, a considerable improvement is often possible by installing one. Chapter 6 shows how receiver signal/noise performance can be improved by the use of a low-noise transistor amplifier, and relative to distribution amplifiers and translators of shared aerial systems, the improvement is usually above that possible on an ordinary receiver because in general the noise performance of, say, a television tuner is better than that of the shared aerial front-end equipment.

In cases of marginal noise performance even when a masthead amplifier is employed, special attention should be given to the coaxial feeder from the masthead to the head equipment. It is essential that cable of the lowest possible loss be employed. It may also pay to include a low-noise transistor amplifier at the ground end of the downlead in addition to a similar amplifier at the masthead.

It sometimes happens that noise on one or more channels develops after the system has been in operation for some period of time. This could be caused by deterioration of an early valve or trouble in the masthead amplifier, or even deterioration of the aerial or coaxial downlead. It is also worth remembering that after a high wind at a lofty site the aerial may no longer be on beam. A substantial loss in signal strength could occur in this way with a highly directional aerial, particularly in an area of mediocre signal field. It always pays to check the orientation of the aerial after a high wind if the system is to operate continuously at top performance.

Another important aspect of system noise is that it tends progressively to get worse over the network. Thus, if the signal is noisy to start with, then it may well be intolerable towards the end of the system. This is because the network noise increases by 3 dB each time the number of repeaters is doubled. This would apply to the larger system in which repeater amplifiers are cascaded to maintain the required signal levels over an extended network.

Intermodulation Effects. These are caused by the creation of sum and difference frequencies due to the presence of two or more signals in the system. The sum and difference frequencies result from non-linearity in equipment, particularly amplifiers (i.e., amplitude distortion), and the nature and amplitudes of the spurious signals are affected by the equipment or system transfer characteristic. At low-level operation the transfer characteristic of an amplifier, for instance, is of maximum linearity. As the signal level is increased, however, the linearity deteriorates until, at overload conditions, non-linearity is substantial and intermodulation effects can be quite severe.

Fortunately, most low-level intermodulation components fall outside the normally carried channels, but there are exceptions and where the non-linearity is excessive weak high order intermodulation components can often be observed as beat-interference (i.e., patterning) on the system channels. An example of intermodulation that can occur in a wideband system prior to overload conditions is the 44·1 MHz beat between f.m. sound at 89·1 MHz and the vision carrier of Channel 1 television at 45 MHz. This beat, of course, is within the passband of receivers tuned to Channel 1, so these receive two signals, one at 45 MHz and the other at 44·1 MHz, a difference of 900 kHz, which can manifest as a bad pattern on vision.

Like noise, intermodulation increases on a system of cascaded repeaters by 3 dB each time the number of repeaters is doubled.

Cross-Modulation Effect. This differs from intermodulation in that it represents the modulation of one carrier on the system being superimposed upon another modulated (or unmodulated) carrier on the system. Thus, on a system suffering from cross-modulation one sees a ghost picture of another channel "floating" on the picture of the tuned channel. In severe cases the unwanted sound may also be heard on the wanted sound. Moreover, the vision modulation may be heard as a buzz on the wanted sound.

Cross-modulation is the biggest hazard of shared aerial systems, especially the larger, extended type in which a number of cascaded repeaters are employed. Freedom from cross-modulation in a large-scale system, coupled with low-noise performance, reveals that the system has been very well engineered. A poorly engineered system, taking into account the equipment, is always troubled with cross-modulation.

Although cross-modulation may not be noticeable by subscribers towards the head end of a system, it could be severe towards the far end of the system,

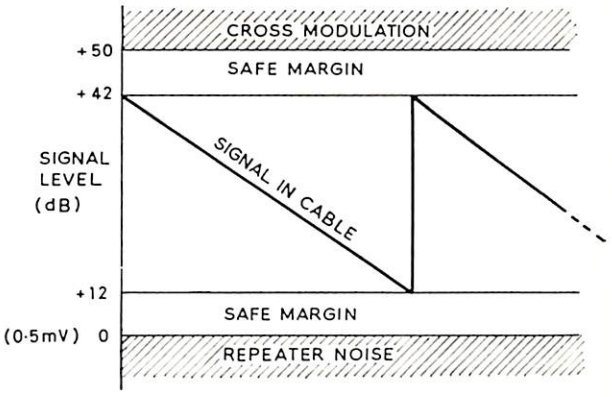


FIG. 7.15. *Showing the cross-modulation and noise working limits of a repeater. The dB values refer to one vision carrier only when the repeater is handling a multiplicity of carriers. 0 dB is scaled to 0·5 mV. The levels illustrated will differ between the various types of repeaters available and are not typical.*

after a number of cascaded repeater amplifiers. This is because it increases by 6 dB each time the number of cascaded repeaters is doubled. Whether or not it will be present at the tails of a system depends on the level of the signals in the repeaters.

If the repeaters are working well below full-output or overload conditions they are working under linear conditions, and it is non-linearity that gives cross-modulation, as intermodulation. Amplifiers are specified as having a maximum output at a particular cross-modulation ratio, expressed in decibels. For cross-modulation to be invisible, its components must be about 200 times (46 dB) below the wanted signal. If a small system uses only one amplifier system which is specified as having an output of 200 mV at a cross-modulation of 46 dB, then the full output could be used with the knowledge that cross-modulation would not be troublesome (in practice, however, a margin of 6 dB would be adopted by prudent users, so only 100 mV would be taken from the amplifier).

When the number of amplifiers in cascade is increased, then the full output should not be attempted from subsequent amplifiers since the overall cross-modulation performance is deteriorating as the number of amplifiers is increasing.

The plan is to adjust the level of the signals on the system so that there is adequate cross-modulation margin, bearing in mind that the attenuation of the cable will vary with changes in temperature, yet consistent with good noise performance and the planned level of signals at subscribers. Of course, it will be evident that if the system was wrongly planned these conditions could never be achieved.

What would happen is that the signal level would be reduced to eliminate cross-modulation, and this would reduce subscribers' signal levels, causing their sets to produce noise, and it would also put noise on the system due to insufficiently high signals at the repeater inputs. Fig. 7.15 shows the "sand-

wich" in which amplifiers should be operated. It will be seen that the signal in the cable starts at 42 dB (here, incidentally 0 dB is referred to 0·5 mV) and drops to 12 dB. The signal is restored to its original 42 dB by the addition of another repeater.

The diagram supposes that the amplifier requires an input above 0·5 mV for good signal/noise performance (better than 46 dB) and that cross-modulation commences (below 46 dB) when the output signal is 50 dB (that is about 158 mV when 0 dB refers to 0·5 mV). Margins of 8 dB for cross-modulation and 12 dB for noise are thus obtained.

Another point to remember is that if a system is operating on, say, two television channels (two sound carriers and two vision carriers) with inadequate cross-modulation margin, the addition of a third channel, such as BBC2, could well run the system into cross-modulation if it is attempted to run the new channel at the same level as the original two channels. The only solutions here are either to run all carriers at lower level or to redesign the whole system. The first method could cause subscriber trouble in view of the reduced signal input, while the second could be very costly.

Radiation from Main Cables. This trouble could well be caused by poor cable matching, the use of ordinary television downlead with insufficient outer conductor density, or too high a signal level in the cables.

Signal Pickup on Subscribers' Downleads. This can happen in areas of a high local signal field. The solution lies in the use of double-screened downleads and take-off matching to the top of the downlead.

Set Injecting Interference into System. Some receivers have a high level of local oscillator signal at their aerial terminals and this is injected into the system, via the take-off. In some cases, the oscillator signal or its harmonic corresponds to the passband of a channel used on the system. Thus, the injected oscillator signal can cause patterns on certain channels. The solution lies in increasing the take-off attenuation between the offending set or sets and the network cable. Directional couplers can be used which have a high value of reverse attenuation.

Lack of Balance of Signals at Subscribers. If the signals are balanced in the main cable, one channel being excessively above another in level or the sound or vision being severely unbalanced could be caused by standing waves on the subscriber's downlead. The solution lies in loading at the top of the downlead with a resistor equal to the Z_0 of the cable.

Lack of Balance of Signals over the Network. This is caused by standing-wave conditions on the network cables due to poor matching at network equipment, discontinuity of cable impedance, poor cable, damaged cable due to poor installation, trouble in an equalizer or incorrect adjustment of launching signal levels or repeater signal levels.

CHAPTER 8

Radio and Television Interference

BECAUSE interfering signals possess the characteristics of electromagnetic radio waves, radio and television receivers are affected by their presence, and some symptoms of interference have been explained and illustrated in Chapter 1.

No receiver can be made completely immune to interference. So far as the receiver is concerned, it deals with interfering signals in exactly the same way as wanted signals. There are various arrangements that can be introduced into receiver circuits to reduce the response to certain kinds of interfering signals, but excessive application of this sort of suppression in the set itself can adversely affect the quality of the wanted signal. The most satisfactory solution to any interference problem lies outside the receiver: that is, in having either the interfering source eliminated or the radiated signal field reduced in intensity by the application of source suppression.

It must at once be made clear that 100 per cent suppression at the source is virtually impossible; and it is rarely possible to have the source eliminated! If equipment or machinery is producing electromagnetic radiation, it is a very difficult problem to prevent some of it leaking into the ether. Moreover, if a device produces electromagnetic radiation as the result of its normal action, it is almost impossible (completely impossible in some cases) to prevent this happening to some degree—even by the use of source suppression —without upsetting the action of the device.

Thus, we are left with the problem that some interference is likely in the vicinity of the receiving system. The local solution is to make sure that as little of it as possible reaches the receiver. In other words, we must keep the signal/interference ratio as high as possible so that the wanted signal is always far stronger than the interfering signals. Earlier chapters have shown that for interference to have insignificant effect on an a.m. transmission, it should be 200 times below the wanted signal on vision and at least 100 times below the wanted signal on sound.

Much interference that causes trouble on a.m. radio and television "looks" to the set like an amplitude-modulated signal, and so is picked up mostly by a.m. equipment. From this aspect, f.m. equipment should not be

affected by this sort of interference, therefore. This is true to a large extent, assuming that the f.m. set has good amplitude suppression features, but it can be shown that a.m. signals and interference can give rise to a by-product f.m. signal, and to this the f.m. receiver may respond (see, for instance, the author's *FM Radio Servicing Handbook*).

Interference suppression can be tackled in five ways by

eliminating the source;
suppression at the source;
screening the source;
inserting suppression circuits in the receiver;
securing a sufficiently high signal/interference ratio at the set.

The first method is not generally practical, and though under certain conditions the Post Office will prohibit the use of equipment that is radiating abnormally, this is a matter of law and hard-and-fast rules cannot be given here. However, should a faulty receiver be radiating to the extent of making it impossible for neighbours to listen to their radios or watch their televisions, it is quite in order for those affected to register a formal complaint with the Post Office Interference Investigation Department. A form calling for details of the nature of the interference, times that it occurs and so forth has to be completed and a Post Office engineer will be instructed to make investigations.

Normally, it is possible to suppress the interference at source—that is, reduce it to a level that is very low compared with the strength of the wanted signal at the receiver. If the equipment is radiating because of a fault, bad design or incorrect application, the Post Office can insist that it is not used until it is restored to normal operation. It should be recorded that the Post Office department dealing with interference is highly co-operative with radio and television dealers, manufacturers of equipment, and with viewers and listeners, every effort being made to resolve the problem to everyone's satisfaction.

Of course, interference can be expected even from suppressed equipment in cases of poor aerial equipment. Indeed, many complaints of radio and television interference result directly from an inferior aerial and/or earth at the affected set. Bearing in mind that it is impossible to clear the ether of all traces of interference, it is the set owner's responsibility to ensure that his aerial and earth system is designed and installed to give a suitable signal/interference ratio relative to the reception area.

In areas close to a transmitter, of course, quite a simple television aerial, for instance, will usually deliver a signal large enough to outweigh most ordinary domestic and commercial interference. However, in fringe areas and locations on the edge of the service area of a station the signal field is that much weaker, thereby reducing the signal/interference ratio at the set

input. This means that more complex aerial systems are here demanded to maintain a satisfactory signal/interference ratio. These are the areas (they include heavily built up and industrial locations) where radio and television interference can be very troublesome and where special attention must be paid to the aerial and earth system.

To sum up, it is the responsibility of the set owner to ensure that his aerial and earth system is of adequate design and efficiently erected to keep the level of random interference picked up as low as possible and the level of wanted signal as high as possible. Reciprocally, the user of radio and electrical equipment should ensure that radiation is kept to the minimum by the application of suitable suppression and screening, if necessary.

CAR IGNITION INTERFERENCE

One of the biggest problems of interference to television equipment used to be that generated by car ignition systems. Main-road viewers had extreme difficulty in following a programme at peak traffic times, and the trouble was especially severe in fringe, screened and weak-signal areas and where reception was on Band I. This led aerial makers to produce highly directional Band I arrays that had a low response to signals below the axis of the array. Set makers also designed remarkably efficient sound noise limiters and vision interference "spotters". These designs are incorporated in many of today's sets and work very well indeed. Such circuits are explained and illustrated in the author's companion volume, *Television Servicing Handbook*.

The situation is now considerably eased as a result of the Wireless Telegraphy Regulations 1952 (S.I. No. 2023) which make it compulsory for all internal combustion engines of the type that interfere with radio and television to be fitted with suppressors. Thus, it is now only the very old cars that are likely to upset television reception, and many of these are quite effectively suppressed to allow the use of an internal car radio. A display of car electrical interference on the screen of a television set is shown in Fig. 1.16 (*a*), page 31.

The electric ignition spark that is responsible for the interference may only last for a small fraction of a second, but during that period quite a heavy current can develop. It is the purpose of the suppression device to cut down this current amplitude. The suppressor must also damp the oscillatory energy so created. The simplest device for suppressing a car ignition system from the television interference aspect consists of a fairly high value resistance connected in series with the high voltage lead from the ignition coil to the distributor.

These items are specially developed to have high insulation and low leakage properties, and they are designed either to connect in the high-

voltage distributor lead, by cutting the lead and joining it through the suppressor, or to screw into the distributor cap as a kind of adaptor, the suppressor then accommodating the high-voltage cable instead of the distributor cap. These two types are shown in Fig. 8.1.

Modern techniques employ a resistive material as the conductor inside the high-voltage coil-to-distributor cable instead of an ordinary, low-resistance conductor. This avoids the use of a separate suppressor.

For the absolute suppression of interference to permit the use of radio telephones and sensitive car radios, a suppression device in each plug lead is often required. For v.h.f. work, it may also be necessary to employ screened high-voltage cables and, of course, all the other electrical equipment in the car including the dynamo, windscreen wiper, electric clock and so forth may need to be treated separately. Plug-end suppressors are also available for suppressing car radio interference.

HOW INTERFERENCE IS PROPAGATED

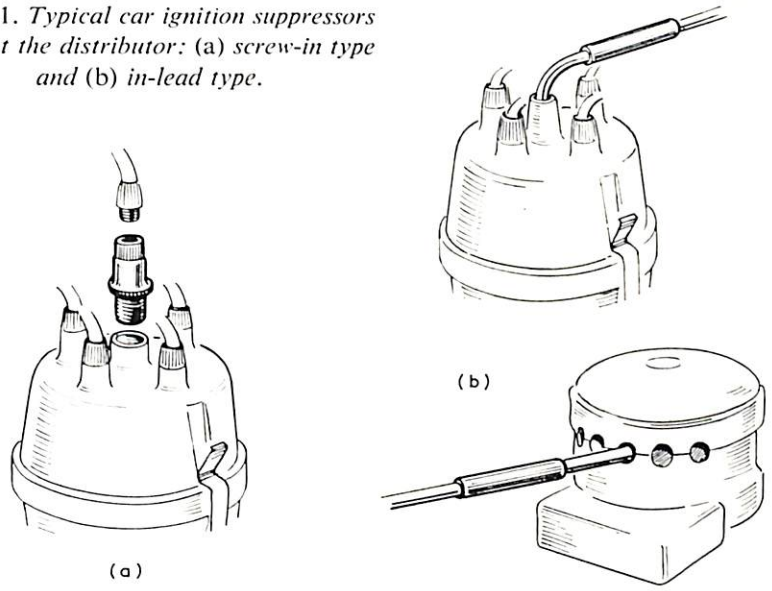
Whenever an electric circuit is completed and then broken there occurs a rise in current and an abrupt decay. The currect collapses to zero almost instantaneously when the circuit is broken, depending on its nature. Transient waveforms of current are thus produced which contain frequencies from low to very high values. The effect is aggravated by the current trying to continue flowing by developing an arc across the contacts, for then steep, irregular transient current waves become superimposed on the ordinary switching waves. Electromagnetic energy is thereby created.

There are two chief ways by which the interference may be propagated from the source to the receiver. Let us consider a brush-type electric motor powered from the mains supply. The supply current circulates in the ordinary way to work the motor, while simultaneously r.f. currents circulate through the motor and wiring owing to the switching and sparking action of the commutator (see Fig. 8.2).

R.f. energy is thus fed into the supply circuits and if a radio set happens to be connected on the same circuit the interfering signals may well get into the set through its mains input and h.t. supply circuits. How far such interference will travel depends on the losses to r.f. signal imposed by the mains circuits. The losses increase with increase in interfering signal frequency, which is why mains-propagated interference is more troublesome on the m.f. radio wavebands than on the v.h.f. and u.h.f. bands.

Since the r.f. currents circulate through the motor and its connecting cables some degree of *radiation* at all frequencies is likely, the effect here being aggravated by the connecting cables and wiring acting rather like a transmitting aerial. The strength of radiation at any particular frequency is then influenced by the length of the effective radiating aerial. It only needs

FIG. 8.1. *Typical car ignition suppressors fitted at the distributor:* (a) *screw-in type and* (b) *in-lead type.*



a few feet of cable for television-band radiation, but several hundred yards is a necessary length for comparable medium-frequency radiation efficiency.

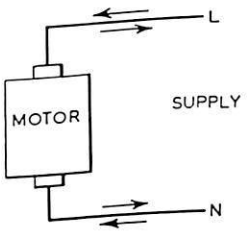
Interference can thus be caused either by direct radiation from the source or by conduction through the mains power supply. A combination of the two is sometimes responsible, but with television reception it is usually the direct radiation mode that contributes most to the effect.

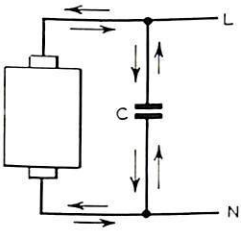
Interference may also be re-radiated and propagated over even greater distances. For instance, radiated interference may be picked up by telephone wires and then re-radiated from the wires at distances considerably removed from the source. This has been known to happen in country areas, the source being corona and arcing at the insulators of mains-supply overhead e.h.t. cables, especially during damp weather. Gutters and water pipes, not normally concerned with electric conduction, can also serve as re-radiating devices for interference signals.

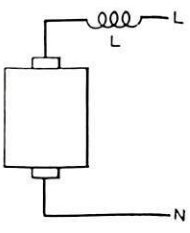
Interference propagation, therefore, can result from (i) direct radiation from the source, (ii) re-radiation from a secondary source, (iii) direct conduction along the mains system and (iv) by field "induction" into the mains system. The first affects mostly h.f., v.h.f. and u.h.f. receivers, the second is virtually a reflection of the first, the third affects mostly long-wave equipment, and the fourth both medium- and long-wave equipment.

The problem, then, is to reduce the intensity of the generated interfering signals and, particularly, to prevent them from circulating in conductors from whence they could be radiated or fed into the mains supply.

There are two important components associated with source suppression







(Left) FIG. 8.2. *The make-and-break action of a motor commutator causes the generation of r.f. currents and these tend to circulate through the supply leads as shown by the arrows.* (Centre) FIG. 8.3. *Capacitor C serves as a short-circuit to the r.f. currents and stops them getting into the supply circuit.* (Right) FIG. 8.4. *Inductor L acts as a high impedance to the r.f. currents and reduces their amplitude.*

networks, the capacitor and the inductor. Let us consider the capacitor first. If of suitable rating, this component can be connected direct across the mains supply without ill effect. A capacitor has a reactance Xc, the value of which is equal to

$$\frac{1}{2\pi fC}$$

Xc is measured in ohms like ordinary resistance, f is the frequency in Hz of the current through the capacitor, and C is its value in farads. At the mains frequency of 50 Hz a 1 μF capacitor has a reactance of a little above 3,000 ohms, but at 500 kHz the reactance of the same capacitor falls to about 0·3 ohms.

Thus, if we connect this capacitor across the terminals of an electric motor, very little reactive mains current will flow, but the capacitor will virtually short-circuit any r.f. signal present. This, shown in Fig. 8.3, will prevent interfering signals getting into the mains wiring, and such a capacitor is often used for reducing medium-frequency interference due to conduction. However, the capacitor does tend to increase the r.f. current in the motor-capacitor circuit and can aggravate radiated interference, particularly at v.h.f. Indeed, it may be found that television interference increases when a simple shunt capacitor is connected as a means of reducing medium-frequency broadcast interference.

The inductor also has a reactance—"inductive reactance", signified X_L. This time, however, its value is equal to

$$2\pi fL$$

X_L is measured in ohms, as before, and L is the value of the inductor in henries. At the mains frequency of 50 Hz a 1 mH inductor has a reactance of 0·3 ohms (excluding the d.c. resistance effect), but this rises to over 3,000 ohms at 500 kHz.

Thus, with increasing frequency, the reactance of an inductor increases

and of a capacitor decreases. While a capacitor may be connected in shunt with an interfering motor, an inductor may be connected in series, as shown in Fig. 8.4. This then offers a high-impedance circuit to the circulating r.f. current, thereby greatly reducing its magnitude. This method of interference suppression is often quite successful at television frequencies.

Suppression is never perfect, but quite good results are possible by the use of good-quality components and correct application. The suppression components must be located as close as possible to the interference source. It is no good applying the suppression at the mains-plug end of a lead to a portable electric drill to clear television interference. The choke or chokes must be placed actually inside the housing of the motor assembly, close to the brushes. Small suppression components are available for such mounting.

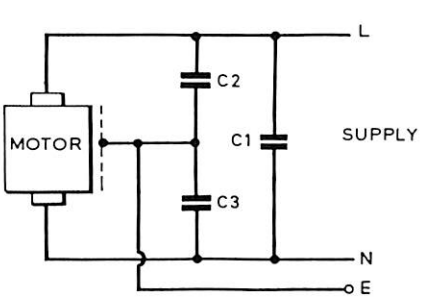
For adequate suppression of both radio and television interference, complex suppressor circuits containing both capacitance and inductance in prescribed quantities are called for.

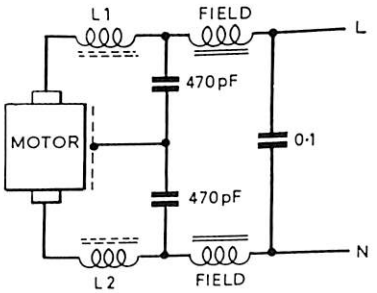
It should be noted that the circulating r.f. currents in the case of conduction interference may not be confined to the live and neutral supply leads, but may circulate round the supply and earth cables, returning to the motor frame and metal housing.

Delta Suppression. Interference resulting from the latter cause is often called asymmetric conduction, and that earlier described symmetric conduction. The circuit in Fig. 8.5 shows how capacitors may be connected in a "delta" network to suppress asymmetric conduction interference.

SAFETY ASPECTS

As will be seen, two of the capacitors in Fig. 8.5 are connected to the metal frame of the motor or appliance, and since there is always the possibility of the appliance (particularly if of the portable variety) not being efficiently earthed, these capacitors must have a value that would not pass a dangerously high reactive mains current.





(Left) FIG. 8.5. *A delta suppression circuit.* (Right) FIG. 8.6. *Suppression network suitable for the majority of portable electrical appliances.*

The reactance of a 1 μF capacitor at 50 Hz would pass something of the order of 75 mA from the mains supply. This means that in the event of the case not being properly earthed, C2 in Fig. 8.5 could pass a lethal current through a human body which is well earthed. It needs only about 5 mA, as registered through normal skin contact, to promote quite a jolting electric shock.

A British Standard recommends a maximum value for suppressor capacitors occupying the positions such as C2 and C3 in Fig. 8.5 of 0·005 μF. However, the capacitor connected between the live and neutral terminals can be of greater value since this is not returned to the metal body or case of the device. With unearthed appliances having exposed metal work (these are rare nowadays), it may be necessary to keep C2 and C3 below 0·005 μF to minimize the sensation of electric shock. Some people are able to detect a mains current as low as 500 μA.

Suppression chokes should be capable of handling the full appliance current without overheating. Moreover, they should be able to withstand 2 kV r.m.s. between their windings and the frame of the appliance without ill effect. If a fuse is fitted in the plug or in the appliance, this is best rated to correspond to the rating of the suppressor choke.

Although it may be found that interference of some kinds can be reduced by connecting a choke in series with the earth lead, this practice is deprecated since a motor fault could produce a fault current that may well fuse the choke and thus remove the earth, probably without upsetting the apparent performance of the appliance. The metal case of the appliance could then be at full mains potential without the user's knowledge, which would be a very dangerous condition.

INTERFERENCE FROM APPLIANCES

Portable Appliances. Fig. 8.6 shows a television and radio suppression network which can be used with a high degree of success in the majority of

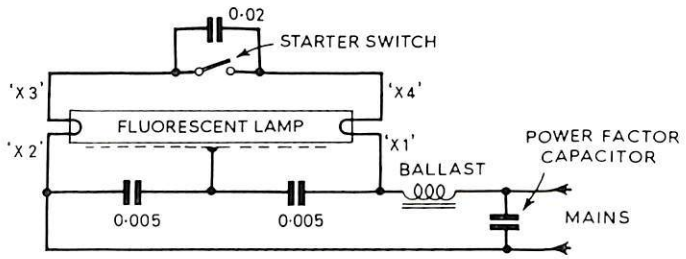


FIG. 8.7. *Fluorescent light interference can be suppressed from television by the connection of small television suppressor chokes in series with the main feeds to the tube. The capacitors shown in this circuit are for radio suppression primarily.*

portable appliances. Inductors L1 and L2 are small iron dust-core television chokes designed specially for suppression applications, and available in a range of current ratings. It is necessary to build the network inside the housing of the appliance for the best suppression.

Fluorescent Lamps. Fig. 8.7 shows the method of dealing with radio interference from a fluorescent lamp. A capacitor is connected across the starter switch and two capacitors are connected in series across the mains supply (after the ballast choke in the unit), their junction being returned to the metal fitting of the lamp, which should be earthed.

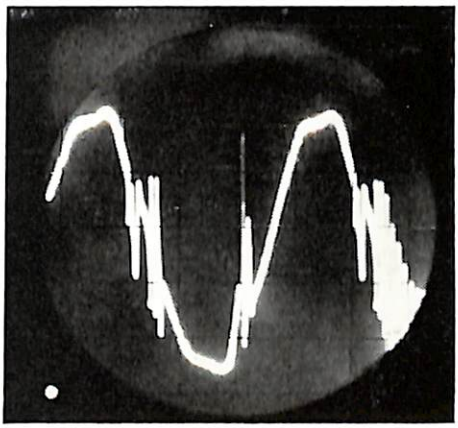


FIG. 8.8. *The radiated waveform from a fluorescent lamp in normal working order.*

Fluorescent lamps can generate quite complex waveforms, and can even oscillate at high frequencies, generating harmonics which enter the v.h.f. bands. Fig. 8.8 shows an oscillogram of the waveform picked up from a fluorescent light simply by coupling several turns of wire round the lamp and returning this to the "Y" input of an oscilloscope. Both radio and television interference is thus produced. On television, particularly on Band I where an indoor aerial is used, the interference can sometimes wipe out a picture by a series of stationary white, dotted and/or patterned horizontal bands. This may be accompanied on sound by a loud, rough buzz. A typical picture interference display is given in Fig. 8.9.

Much of this interference is produced by oscillation created in the tube and the radiation of very short duration pulses of high-frequency content. If a tube is prone to oscillate, it usually does so within 10-15 minutes after it has been switched on and then the effect remains fairly steady.

It is often possible to get temporary relief either by reversing the tube in its holder or by giving it a sharp tap. To effect a permanent cure, it is necessary to install suppression components as in Fig. 8.7 for radio, or to connect a small television choke at point X1 on the circuit for television. Often a single choke is sufficient, but in bad cases two or even four may be required at points X2, X3 and X4. These should be fitted as close as possible to the tube and be located in the lamp housing.

Thermostats. Thermostat switches are another source of interference The spark that is produced at the instant the contacts part generates electromagnetic signals, and the interference effect is often prolonged since the spark may develop into an electric arc which continues until the contacts open

FIG. 8.9. *A typical display of fluorescent lamp interference on a television screen.*

enough to quench it. This may take several seconds or even minutes, during which time extremely bad interference can be generated. Both radio and television interference from this source can be reduced by the circuit given in Fig. 8.10. Here L1 and L2 are small television chokes.

Neon Signs. Neon signs cause a great deal of trouble in towns, but this can be alleviated to some extent by including a resistor of some 50 to 100 kilohms in each high-voltage lead, taking extreme care to maintain good insulation.

Large Appliances. Mains-borne interference (i.e., interference conducted through the mains circuits) can originate from large electrical appliances used in shops and factories and even from electric cookers. In badly affected locations it may be necessary to install h.f. filters in the supply leads close to the mains input to the building which requires suppressing. The filter inductors in this case need to be very large indeed to handle the heavy total currents of the building, and this is really a specialized job outside the scope of ordinary suppression.

Fortunately, the majority of small electrical household appliances are now reasonably well suppressed by their makers in order to conform with the requirements of the Wireless Telegraphy Act. However, there are times when full suppression or extra suppression is demanded and the foregoing will suggest ways in which this can be handled.

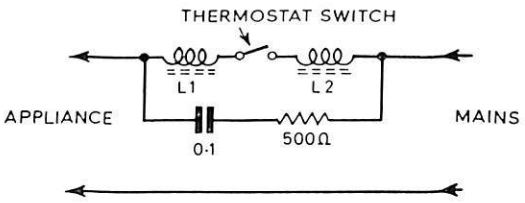


FIG. 8.10. *Interference from a thermostat can be suppressed by this R and C combination. Chokes L1 and L2 help from the television aspect.*

RADIO AND TELEVISION INTERFERENCE

It is very important to remember that a badly suppressed appliance could be lethal, and unless one knows exactly what one is doing, a proficient electrical engineer should be called in to perform the required operations.

TELEVISION TIMEBASE INTERFERENCE

On the long-wave BBC Radio 2 programme in particular line timebase interference from television sets causes most trouble. It superimposes on the programme when tuned-in a high-pitched whistle and sometimes a rough buzzing noise. This interference is both radiated and induced from the line timebase output stage of the set. Early sets were considerably more prone to this emission than are present-day models, and various artifices were adopted to reduce it.

It is, of course, impossible to "suppress" the line timebase of a set, for to do so would put the timebase out of action. Here, then, is a typical example of where it is necessary to *screen* the interfering source. Radiation occurs mostly from the line output transformer and this can be contained in a screened compartment in the set. However, after a servicing operation the screen may not be fitted properly; the top may have been left off or the whole cage assembly may not have been put back. In these instances, radiation could well cause trouble on nearby radio sets.

The interference is often aggravated by a poor aerial and/or earth system on the radio set. The radio aerial should not be routed too close to the television aerial, downlead or receiver and, if necessary, a matched anti-interference radio aerial should be used with a screened downlead.

The interference may be induced into the radio receiver. This can happen if the television set happens to be on the same dividing wall as the radio set. In a semi-detached house, for instance, one neighbour may have his television set placed against the wall dividing the two dwellings while the other neighbour may have his radio set close against the other side of the wall.

Steps should be taken to separate the two sets as far as possible. Where this fails to effect a cure extra screening may be necessary inside the television set's cabinet. Painting the inside of the cabinet with a metallized or conductive paint often helps, but extreme care must be taken to prevent any of the paint spilling on to the outside of the cabinet or anywhere where a person could make contact with it, since it will be in electrical contact with the set's chassis, and this could be connected to the live side of the mains supply!

Coating the inside of the cabinet with a metal foil represents an alternative method of screening. Again, it is essential to ensure that the foil cannot be touched by anyone handling the set.

Reversing the mains connections of the radio or television set is also

worth trying since some of this sort of interference, affecting long-wave reception, is mains-borne.

To prevent the interference getting into the mains system a pair of series-connected capacitors can be connected across the supply at the television set, and the junction taken to a good earth point. 0·005 μF capacitors are suitable, but they must have a 240 V a.c. working specification.

A similar capacitor filter can also be employed at the radio receiver mains input. This will prevent any interference in the mains system from getting into the set through the h.t. circuits.

In the case of a portable receiver being affected by line timebase interference, the set should be carefully orientated for best signal/interference ratio. When the source is at right-angles to the ferrite rod aerial in the set, pickup is at a maximum. Thus, the set should be adjusted until the end of the rod points to the source.

Locating Broadcast Interference. A small portable set of this kind can be employed to help locate broadcast interference. The idea is to orientate the set to the null point of the interference (minimum pickup). A set with a ferrite rod aerial is quite sensitive in this direction, a few degrees either side of the null point bringing the interference back again. When the set is so positioned, one end of the rod is pointing directly to the source. A few tests will soon determine which end of the rod is so pointing.

R.F. INTERFERENCE

Most interference coming from electric motors, thermostats, switches, car ignition and the like has the nature of pulses and is thus called "impulsive interference."

Another type of interference which affects both radio and television reception results from an r.f. signal either in the main passband of the equipment or in a spurious passband. This is called "r.f. interference". Under this heading comes interference originating from diathermy apparatus, radiating local oscillators, mobile transmitters, amateur transmitters, and a multitude of present-day devices employing oscillators.

R.f. interference generally upsets the picture more than the sound. It manifests as pattern effects on the picture and whistles on the sound. If the r.f. signal is modulated by the mains supply frequency, as it may be when it emanates from diathermy or medical apparatus, it produces a band of "herring-bone" pattern on the picture and a raw a.c. buzz on the sound.

A constant-frequency r.f. signal will give rise to a steady pattern on the picture, but if the frequency has a drifting tendency, then the pattern formation will alter as the interfering signal frequency changes. The patterns are created by the interfering signal (let us call it f_1) heterodyning with the vision carrier (f_2). This gives rise to a third signal of $f_1 + f_2$ and a fourth signal of

$f_1 - f_2$ or $f_2 - f_1$. One of these spurious signals falls within the vision passband and is thus applied together with the picture modulation to the modulator electrode of the television picture tube.

The spurious frequency has a bearing on the nature of the pattern produced. For example, when the two signals generate a spurious signal of about 2·5 MHz on a 405-line system, the scanning lines break up into a series of dashes, with a consequent fall in picture definition. As the spurious signal frequency reduces, the pattern first takes the form of vertical bars, changing to horizontal bars as the frequency falls below the line timebase repetition frequency.

From the sound aspect, the spurious signal is accepted by the sound passband and like the sound modulation is demodulated by the detector, thereby producing the whistle.

Beat notes (whistles) are very bad at the top end of the medium waveband due to the closeness of stations at that end of the dial. If the separation in terms of frequency is within the audible spectrum, then a whistle at that frequency will interfere with the wanted programme. The solution to this problem lies only in reducing the passband of the i.f. stages, but when this is done the upper-frequency sidebands of the wanted signal are suppressed or greatly attenuated and the reproduction then suffers a loss of treble. This, as we have seen in earlier chapters, is the major shortcoming of medium-frequency reception. The trouble is eliminated completely by the use of the v.h.f. f.m. system, and for reasonably high quality reception it is essential that this system is adopted.

R.f. interference can be generated by faulty equipment. For instance, the decoupling of a television set may fail and cause the set to oscillate. Such oscillation may beat with the vision (or sound) signal at an affected receiver picking up the emission and cause patterns (or whistles) as already explained. An oscillating aerial amplifier or set-side pre-amplifier or signal booster can also cause the effect. In this case, however, incorrect loading from the aerial to the amplifier or from the amplifier to the set could be responsible (see Chapter 6).

A typical display of r.f. interference on a television picture is shown in Fig. 1.16 (*b*), page 31.

Maladjustment in the television receiver itself can also aggravate pattern interference troubles. On the 405-line system, for instance, the sound carrier of an adjacent channel signal can beat with the vision carrier of the wanted channel and produce a 1·5 MHz pattern on the screen. This takes the form of slightly diagonal lines (almost vertical), the intensity of which is governed partly by the strength of the adjacent channel sound carrier and partly by the degree of adjacent channel rejection given by the set.

The pattern is of 1·5 MHz characteristics since the vision carrier of one

channel is separated by that frequency from the sound channel of the upper adjacent channel. All sets feature adjacent channel rejectors to suppress this sort of pattern interference, but if the rejector is out of adjustment and/or if the adjacent channel sound carrier is very strong it may well break through to the picture of the wanted programme.

The effect is often aggravated in areas where two adjacent channels can be received and where an aerial booster is used to strengthen the weakest signal of the two. The amplified adjacent sound carrier then tends to outweigh the nominal attenuation of the set's rejector.

INTERFERENCE ACCEPTANCE CHANNELS

Interfering r.f. interference can gain admittance to the affected receiver either through the main acceptance channel of the set (that is, when the signal is close to the frequency of the sound or vision carrier) or through a spurious acceptance channel. A spurious acceptance channel would be the i.f. channel or the "image" or "second channel". Although the selectivity of the circuits prior to the frequency changer of a receiver will limit the response of the receiver at frequencies far removed from the main or fundamental acceptance, a very strong r.f. signal will, nevertheless, gain admittance through the aerial circuits and cause pattern disturbances.

This is particularly true of the "second channel" acceptance. The second channel can be discovered by subtracting twice the i.f. from the tuned frequency of the receiver, where the local oscillator frequency is *below* the signal frequency; and by adding twice the i.f. to the tuned frequency, where the local oscillator is *above* the signal frequency.

Sets whose intermediate frequencies are close to the tuned frequency will have a reasonable response through the aerial circuits at the i.f., and spurious signals arriving at the aerial of a frequency within the i.f. passband can cause trouble. However, many sets have their i.f. response minimized by the use of i.f. rejectors in the aerial circuits. If pattern or whistle effects are caused by i.f. breakthrough, therefore, special attention should be given to the i.f. rejector alignment.

Harmonics of the local oscillator can also produce a response in the i.f. channel due to a strong signal falling outside the tuned passband of a set. Take a set tuned to Channel 4, for instance. If this has a vision i.f. of, say, 10 to 13 MHz (a much higher i.f. is now used, however), and if the sound i.f. is below the vision i.f., the local oscillator would be working at about 49 MHz. The second harmonic of this 98 MHz, meaning that the presence of a signal around 86 MHz would produce a spurious interfering signal falling in the vision i.f. passband.

An example of possible second-channel interference in the u.h.f. bands is where a set is tuned to Channel 23 whose vision carrier is 487·25 MHz.

The standard 625-line i.f. is 39·5 MHz and the oscillator is this amount *above* the tuned signal frequency, which works out in this case to 526·75 MHz.

Now, as Channel 33 has a vision carrier of 567·25 MHz, this could beat with the Channel 23 oscillator frequency of 526·75 MHz and produce a signal whose frequency is only 1 MHz removed from the main i.f. Thus, a set receiving Channel 23 could have a 1 MHz pattern on its picture due to the front end of the set also passing a Channel 33 signal! This is avoided in practice by the u.h.f. tuner being endowed with adequate pre-frequency changer selectivity. A minimum rejection ratio of 53 dB should be provided by set makers; but malalignment could impair this ratio.

LOCAL OSCILLATOR INTERFERENCE

Television and radio receivers are sometimes the cause of pattern interference on neighbouring sets. This happens mainly in areas where distant stations are received as well as the local stations. Depending on the i.f. combination of the offending set and on the channel to which it is tuned, the local oscillator may be working at a frequency which falls within the sound or vision passband of a station which is received in the area.

All sets radiate at their local oscillators to some degree and not much can be done to eliminate this. Normally, the frequency of the radiated signal is well away from the main or spurious responses of sets tuned to the local channels, but when more distant stations are also received in the area oscillator signals can be coincident with an acceptance channel of a set tuned to a local or distant station.

If the local oscillator signal is getting out of the aerial a coaxial open-circuit quarter-wave stub connected in parallel with the aerial terminals and adjusted to respond to the oscillator frequency can reduce the strength of the signal actually applied to the aerial, and thus reduce the radiation problem. This happens because the end of the stub connected across the aerial terminals "looks" like a short-circuit to the oscillator signal.

Apart from attempting to suppress the radiation at source, other methods can sometimes be adopted to eliminate the patterns at affected sets. The problem lies first in establishing the frequency at which the interference is getting into the set and secondly in clearing the spurious response at that frequency. If the interference is exactly on the carrier frequency, little can be done at the set. The source must then be located and cleared.

If the interfering signal is a little to the side of a carrier, a high-Q rejector connected in the aerial circuit may help. This can be arranged to put a dip in the set's response at the interfering frequency. The rejector can have the circuit given in Fig. 8.11. It should be built into a screened box and connected as close as possible to the aerial socket of the set. The coil and capacitors specified on the circuit are suitable for Band III frequencies.

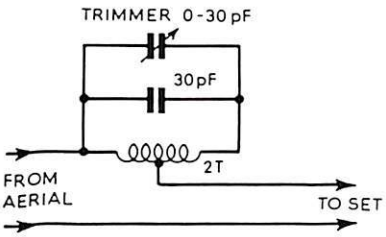


FIG. 8.11. *A high-Q television rejector circuit. This is suitable for connecting in the coaxial downlead and the inductor and capacitor values are suitable for Band III channels.*

In many cases the interference gets in either through the second channel or the i.f. channel direct, in spite of internal rejector circuits in the set. In these cases extra external rejection can solve the problem.

If the spurious response of the set is above the carrier frequency, a low-pass filter can be connected in the aerial downlead. This will introduce a large amount of attenuation at all frequencies *above* the carrier and thus allow the passage of signal at frequencies below the carrier—including the carrier, of course.

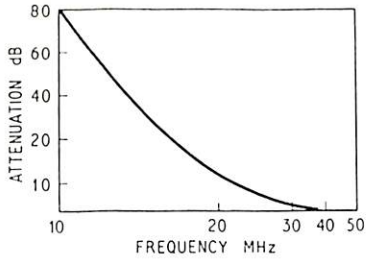
If the interference is below the carrier, which is usually the case, a high-pass filter is needed. This has characteristics opposite to those of a low-pass filter. High-pass means that all frequencies above, including the carrier, are passed, while signals at lower frequencies are heavily attenuated. The response of a high-pass filter is shown in Fig. 8.12, while a circuit of the most frequently used high-pass filter is given in Fig. 8.13.

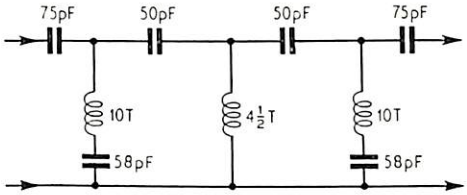
Care must be taken not to introduce a filter into a common aerial downlead carrying signals of all bands, as the filter may then attenuate some of the signal needed by the set. The best idea is to put the filters in the leads which are carrying only one channel of frequencies. For example, if a low-pass filter is employed in a common downlead to suppress pattern interference on Band I, the filter would also block the Band III and possibly Band II signals from the set!

F.M. INTERFERENCE ON TELEVISION

In some areas a powerful Band II f.m. signal can cause pattern interference on television sets. The interference gets in either at the set's second-channel acceptance, where the intermediate frequencies are 16 to 19·5 MHz, or at the local oscillator frequency (thereby producing an interfering i.f. signal), where they are 34 to 38 MHz. The solution lies in the use of a Band II rejector in the television aerial input circuit. A suitable coaxial stub filter has been evolved by the BBC for inclusion in the aerial lead of the television set. This is shown in Fig. 8.14. The lengths of the various coaxial elements are calculated on the basis of cellular dielectric cable.

As much of an interference as the other effects so far described is "noise". On sound this produces a hissing noise and on the picture it gives a background of grain, as shown in Fig. 8.15.





(Left) FIG. 8.12. *Response characteristics of a high-pass filter.* (Right) FIG. 8.13. *Circuit of two-stage high-pass filter. The coils are* $\frac{7}{8}$ *in. diameter self-supporting.*

Noise has been dealt with extensively in earlier chapters, where it has been shown that it can only be eliminated on vision by making the wanted signal at least 200 times stronger than the generated noise signal, and on sound by making the ratio at least 100 times. The signal/noise ratio can be improved by either making the receiver more noise-free and/or the aerial signal stronger. The latter is sometimes possible by the use of a low-noise transistor aerial amplifier, as explained in Chapter 6, while for the former a more efficient aerial system is demanded, as explained in Chapter 4.

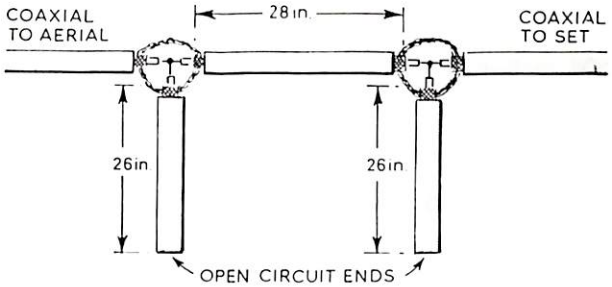


FIG. 8.14. *A stub-type rejector for eliminating f.m. interference from television reception.*

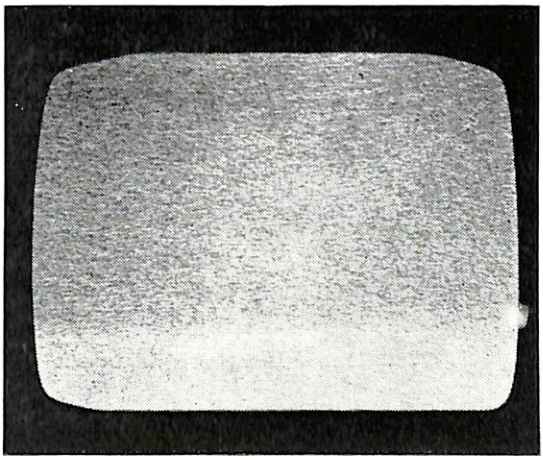


FIG. 8.15. *Display of "noise" as seen on a television screen.*

CO-CHANNEL INTERFERENCE

This is one of the worst of the interference effects on both television and Band II f.m. sound radio. It has been dealt with in some detail in earlier chapters of this book, its cause being fully expounded in Chapter 1, page 25, while ways of discriminating against it in terms of the aerial and its orientation are given in Chapter 4. A picture of the effect is given in Fig. 1.12, page 25, and it is further illustrated in Fig. 8.16.

There is nothing that can be done at the set to alleviate this effect. Attention must always be focused on the aerial system, the aim being to secure the greatest discrimination against the unwanted signal relative to the wanted signal; that is, to secure the best possible signal/interference ratio.

THE BOVILL FILTER

It has been mentioned that interference can arise on the Band I channels, in early spring and summer months especially, because of abnormally high tropospheric and ionospheric activities. The interference is caused by the signal of a distant television transmitter, close to the frequency of the local transmitter, arriving at often considerable strength at the aerial of the affected receiver. The nature of interference produced is shown in Fig. 8.17. It is well known to Channel 1 and 2 viewers living in coastal areas, since in many instances the interfering signals emanate from European television stations.

An interesting device to combat such interference is the Bovill notch filter developed by Charles B. Bovill, consultant engineer, based on a G.P.O. design. The filter is connected in the aerial downlead and here serves to "notch out" any interfering carrier sufficiently close to the Band I vision carrier to cause pattern interference. The author has undertaken a series of prolonged tests with the Bovill filter and its performance under some con-

FIG. 8.16. *A severe case of co-channel interference.*

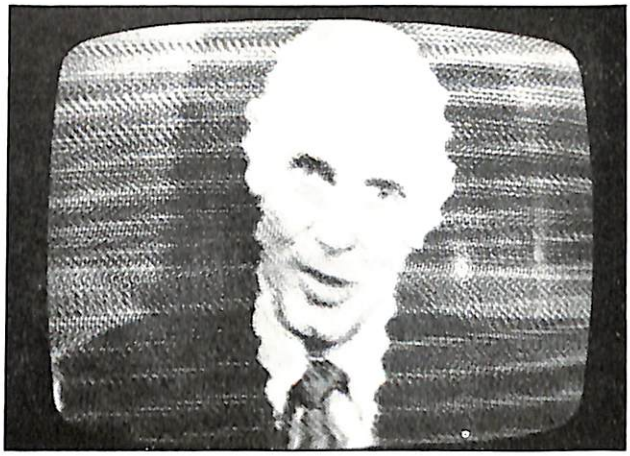


FIG. 8.17. *Untouched photograph of a Band I television picture badly affected by sporadic E conditions.*

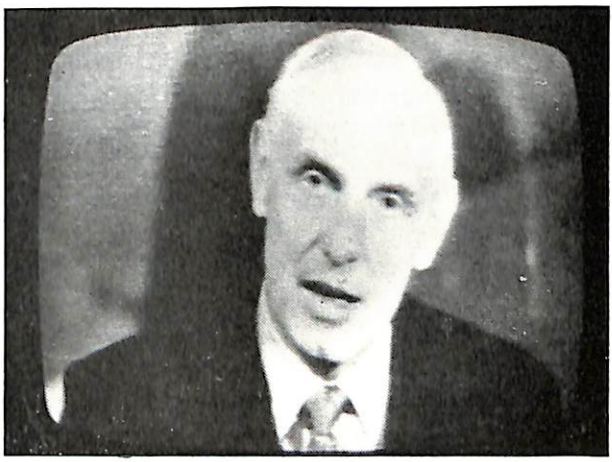


FIG. 8.18. *The same transmission as in* FIG. 8.17, *but received with a Bovill filter connected in the aerial downlead.*

ditions is well proved by the relatively clear picture in Fig. 8.18. This is from exactly the same interference-laden signal responsible for the picture in Fig. 8.17, but with the filter connected and accurately tuned and balanced.

The filter is of rather special design, the basic circuit being given in Fig. 8.19, and has some things in common with the parallel-T tuned filter where the tuned circuit losses are balanced out by an adjustable resistance. The resulting high-Q effect allows the filter to dip deeply into the aerial/receiver response and thus "extract" wholly the offending carrier—even though this is very close to the wanted signal's vision carrier—without unduly attenuating or affecting the wanted signal. The filter is tuned to the interfering carrier by the tuned circuit and maximum attenuation is applied by the resistor balancing-out the losses. The inside of the filter is shown in Fig. 8.20.

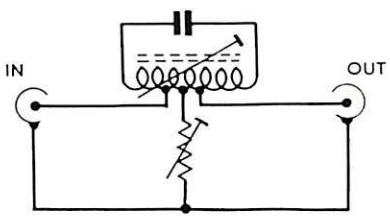


FIG. 8.19. *Basic circuit of the Bovill notch filter.*

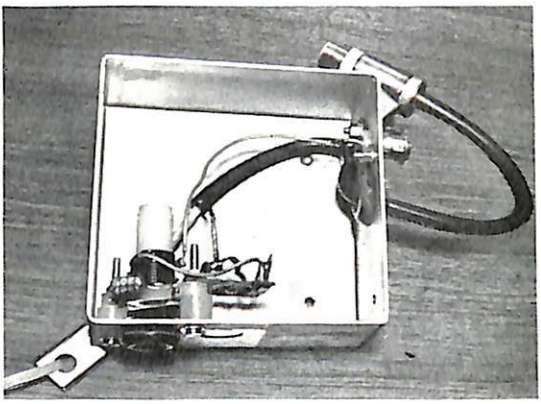


FIG. 8.20. *Inside of the Bovill filter.*

The Bovill filter gives some 40 dB attenuation at its tuned and balanced frequency, while only attenuating the wanted carrier by a few decibels, depending upon its distance from the unwanted carrier. In severe cases of tropospheric and ionospheric (i.e., sporadic E) conditions, a number of interfering carriers may be picked up by the affected installation. The filter can only delete one of these, of course, but it is understood that the design may be developed to embrace more than one rejection frequency, along the lines of a comb filter.

APPENDIX I

AERIAL DIMENSIONS

Radio and television enthusiasts with a desire to construct their own aerials are referred to the dimensional formulae given on page 74 for general applications. To avoid the need of working out element lengths and spacings of Yagi arrays, however, Table A.1 can be consulted. This table relates to the type of aerial shown in Fig. A.1, which on Bands I and II is up to three elements (folded dipole plus reflector and director), on Band III up to ten elements (folded dipole plus reflector and eight directors), and on the u.h.f. groups of channels is 16 elements.

While the v.h.f. aerials may be made in the form of three-element, two-element (dipole plus either a reflector or a director), or single-element (dipole) arrays, all 16 elements should be retained for u.h.f. arrays to maintain sufficient bandwidth of the particular channel group.

Two-element and single-dipole v.h.f. arrays use a straight dipole instead of the folded dipole that is necessary to facilitate matching when three elements are used. The length of the folded dipole is calculated from half-way along the bend at one end to half-way along the bend at the opposite end.

The v.h.f. aerials use a single rod element as the reflector, while the u.h.f. aerials employ a reflector composed of a series of four rods secured to a cross-member, as shown by the left-hand section of Fig. A.1. These four reflector rods are arranged to be in the same plane as the other elements of the aerial. Thus, the reflector end of the main aerial is secured to the centre of the cross-member holding the four reflector rods, at point X on the left-hand section of Fig. A.1.

The centre point of all the parasitic elements and of the closed length of the *folded* dipole are all at zero signal potential and thus may be in electrical contact with the reflector cross-member and the main aerial cross-boom without ill effect. The open ends of the folded dipole must be insulated from each other and from the cross-boom, for across these points the coaxial downlead connects. When a *straight* dipole is used, the two ends of the break in the centre must likewise be insulated from each other and from the cross-boom, this being the point of feeder connection.

The distance between the two adjacent ends of the dipole half-sections should not exceed 1 in., preferably $\frac{1}{2}$ in. on the u.h.f. aerials.

Insulators for the centre of the dipole and clamps for fixing these to the aerial cross-boom are available commercially, as also are the various other items required for an aerial of this kind, such as alloy rods for the elements, cross-boom and cross-member, clamps for securing the elements to the cross-

boom, couplings from a cross-boom to a reflector-system cross-member, clamps and cups for coupling a mast to the cross-boom and brackets, and items for chimney or wall mounting.

The elements can be made from tubular rods of about ½ in. diameter, while the cross-member and cross-boom can consist of an alloy tubular rod of about 1 in. diameter.

Table A.1

DIMENSIONS FOR AERIALS IN FIG. A.1

Channel	*Dimensions (in.)*										
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*a*	*b*	*c*
BAND I											
1	134	127	117	—	—	—	—	—	67	40	1·5
2	117	111	101	—	—	—	—	—	58	35	1·5
3	107	101	92	—	—	—	—	—	53	32	1·5
4	97	92	85	—	—	—	—	—	49	29	1·5
5	90	85	78	—	—	—	—	—	45	27	1·5
BAND II	66	62·5	58·5	—	—	—	—	—	32·2	19·7	1·5
BAND III											
6	33	31·5	29·5	29	28·5	28	—	—	17·1	8·7	1
7	32·5	30	28·5	28	27·5	27	—	—	16·7	8·5	1
8	32	29·5	27·5	27	26·5	26	—	—	16·3	8·2	1
9	31·5	29	26·5	26	25·5	25	—	—	15·8	8	1
10	29·5	28	26	25·5	25	24·5	—	—	15·5	7·8	1
11	29	27·5	25	24·5	24	23·5	—	—	15·2	7·6	1
12	28·5	27	24·5	24	23·5	23	—	—	14·6	7·4	1
13	28	26·5	24	23·5	23	22·5	—	—	14·3	7·2	1
U.H.F. Groups*											
A (Red)	10·9	10·8	9·5	9	8·9	8·3	8	7·8	4·45	4·45	0·7
B (Yellow)	10·45	8·45	7·4	7·1	7	6·5	6·3	6·1	3·5	3·5	0·7
C (Green)	9·15	7·15	6·25	6	5·9	5·5	5·2	4·8	2·95	2·95	0·7
D (Blue)	10·3	9·2	7·2	6·25	6·1	5·8	5·4	5·1	3·0	3·0	0·7
E (Brown)	10·6	10·4	8·3	7·3	7·0	6·9	6·3	6·2	3·4	3·4	0·7

Channels covered in the u.h.f. groups are:

Group Letter	*Colour Code*	*Channels*
A	Red	21–34
B	Yellow	39–51
C	Green	50–66
D	Blue	49–68
E	Brown	39–68

*Aerials in Groups D and E cater for the non-standard areas only and should not be used in areas which are fully embraced by the channels given by groups A, B and C, even though some of the channels may be covered by the non-standard aerials. However, non-standard aerials in Group B (Channels 39–51) are sometimes recommended for Moel-y-Parc and Saddleworth areas instead of Group E aerials (Channels 39–68) to avoid a required channel falling too close to the aerial response roll-off, which is sawtooth.

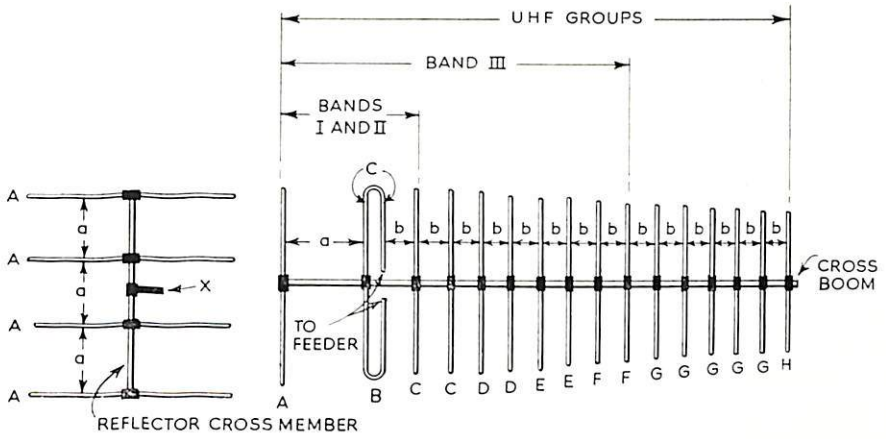


FIG. A.1. *Pattern of general-purpose Yagi array to be used in conjunction with the dimensions given in Table A.*1.

There is a lot of fun in building one's own aerials, and if roof-space or attic mounting is envisaged, the mechanical construction need be nowhere near as robust as on aerials designed for roof and outdoor mounting. Indeed, if one is lucky enough to have plenty of roof space, the various elements can be supported in line from thread secured to a roof beam. The author's roof space carries a conglomeration of such weird aerial arrays for all bands! Nevertheless, they work quite well and can be designed to suit any specific or new requirement.

Incidentally, different dimensions might be obtained by using the expressions on page 74 since these relate essentially to "peaked" dipoles, etc. In the table the dimensions have been modified to give the best (u.h.f.) wideband working. The "spacing" dimensions are between the *surfaces* of the rods, not the centres.

APPENDIX II

AERIAL ERECTION AND THE LAW

Theoretically, planning permission is required for the erection of any outside aerial system. In practice, the rapid development of the television service, coupled with the need for substantially complex aerial systems in fringe reception areas, has made it virtually impossible to issue individual permission for each and every aerial system erected.

Planning permission is required from the local Town and Country Planning Authority for any building, engineering or other operation which one proposes to undertake. Thus, if it is required to distribute signal from

a master aerial system through coaxial cables over land and property, such planning permission must first be obtained. Similar permission is necessary for the erection of a master aerial, and this may still be required if the aerial is sited on private property, as the aerial system may then materially affect the external appearance of a building, for instance.

Very elaborate private aerials, even though serving only a single receiver, may also require planning permission if they materially affect the external appearance of a building. It would appear that one does not need such permission provided the erection fails to affect the external appearance to any extent—which generally covers ordinary household aerials at the present time.

If the aerial is fixed on property other than that of the owner, permission must be sought from the owner of the property concerned. For instance, if it is proposed to employ the neighbour's side of a shared chimney stack to fix an aerial (probably as an aid towards improved signal pickup), permission must first be obtained.

Some local councils require their tenants to obtain permission in writing for the erection of an aerial system; and there may be certain stipulations that have to be observed. It is always best to check with any landlord, including a private landlord, to avoid possible future complications. Moreover, it is prudent to take out a good insurance against damage that may be caused by the aerial to both property and person.

Before wiring housing estates, flats and the like from a communal aerial system, permission must be obtained from the owners of the property and it may also be necessary to seek a wiring concession from the local council. A Post Office "Relay" licence is also required for such a project.

APPENDIX III

AERIALS FOR COLOUR TELEVISION

It is essential that aerials used for the reception of colour encoded signals have a non-distorted bandwidth extending at least over the channel. Normally, a u.h.f. aerial would have a bandwidth embracing a number of channels, but the response is sawtooth shape, falling sharply at the higher channel limit, thereby affecting the relative gain at the subcarrier frequency on higher-than-designed-for channels. This can result in poor colour rendering and de-saturation of the coloured reproduction.

While the P.A.L. system, adopted in Great Britain, is somewhat less sensitive to phase errors and changes of the subcarrier signal, it is nevertheless desirable to avoid phase distortion in the aerial system, and to this end the aerial's termination should appear truly resistive at all frequencies within

the channel bandwidth. The same applies to aerial amplifiers, filters, etc., connected to the installation. Phase shifts can change the hue on the (American) N.T.S.C. system, but phase errors up to 70 deg. can be tolerated on the P.A.L. system.

Since colour sets are considerably more expensive than their monochrome counterparts, it is only logical that special attention should be given to the aerial system used with a colour set. A signal that is just about sufficient for black-and-white reproduction should never be used for colour, and every attempt should be made to increase the signal level *at the aerial* by at least 6 dB.

Colour sets can be used on communal aerial systems only if the systems themselves afford adequate channel bandwidth and low phase distortion. Real trouble can result if the system is approaching instability threshold, if the response over the channel is badly undulating—giving emphasis or de-emphasis to the colour sidebands—and if the signal levels are abnormally low either at the master aerial or at the receiver outlets.

APPENDIX IV

AERIALS FOR STEREOPHONIC RADIO

Radio stereo programmes are transmitted by the BBC in Band II, the process requiring a stereo decoder at the receiver or tuner. All Band II f.m. aerials are suitable for the transmissions in terms of bandwidth, frequency of tuning, etc., but a limitation may be imposed by the strength of the Band II stereo encoded signals induced into the aerial.

When a *mono* receiver or tuner is responding to a stereo encoded signal the signal/noise ratio is reduced by about 4 dB relative to a non-encoded transmission. In fringe areas, therefore, an extra 4 dB of aerial gain may be required to achieve the original, non-encoded signal/noise ratio. The situation is, however, much worse when a *stereo* receiver (an f.m. set or tuner with a stereo decoder connected) is responding to a stereo transmission. The effect of the pilot carrier and the A-B (stereo) sidebands of the transmission can impair the relative-to-mono signal/noise ratio by as much as 24 dB.

This may not necessarily mean that the aerial has to produce an extra 24 dB signal gain to restore to the mono signal/noise ratio, because the aerial may already be delivering more signal than required for optimum noise mono reception. It does mean, though, that in weak signal areas considerably more attention will have to be given to the Band II aerial, and in some cases it may in fact be necessary to lift the aerial gain by almost 24 dB for a signal/noise performance comparable to mono in the same location and from the same transmitter. In an obstinate case, however, a great deal of improvement can be obtained by the use of a low-noise transistor Band II pre-amplifier, such as the King FM Booster.

APPENDIX V

EARTHING AND LIGHTNING PROTECTION

From the reception point of view a good earth is sometimes almost as important as a good aerial, particularly with regard to the suppression of some types of interference. (This has been dealt with in Chapter 1, page 37.) A good earth is also important from the safety point of view. Modern television sets, however, rarely have provision for the connection of an outside earth, but this is not to say that the low-impedance side of the aerial itself is not earthed, thereby earthing the set through the braid or outer conductor of the downlead.

If the screen of the coaxial feeder is not earthed purposely, it may automatically earth to the guttering, to a water pipe or even to the building itself during wet weather.

Modern sets use the so-called a.c./d.c. technique. This means that the set does not carry a mains transformer with an isolated primary winding. The mains supply is thus in direct connection with the metal chassis and/or h.t. negative side of the set, and the aerial system is isolated from the mains by isolating capacitors. One such capacitor is connected in each feeder conductor circuit.

The capacitors have a relatively high impedance at the mains frequency (50 or 60 Hz), so very little mains current flows under the worst condition: that is, with the supply to the set connected so that the chassis and negative side is at live mains potential and with the aerial feeder earthed. If a good earth is bonded to the feeder outer conductor, failure of one of the isolating capacitors would result in a very heavy fault current back to earth and a fuse somewhere would blow. But if the outer conductor of the feeder is not efficiently earthed, an isolating capacitor in the set could short-circuit and no one would be any the wiser.

If the mains is live-connected, as explained above, the aerial feeder could assume a mains potential some 240 V a.c. above earth. Anyone touching the feeder or the dipole while themselves being in good connection with ground would receive a severe or possibly fatal electric shock. Indeed, there have been cases of aerial erectors having bad electric shocks from this cause.

Clearly, then, a good earth connected to the outer braid of the feeder represents a factor of safety; but in all cases care should be taken to see that the mains is connected so that the neutral line is on the chassis/h.t. negative side of the set. In any event, when adjusting aerials make sure the set is disconnected from the mains supply.

LIGHTNING PROTECTION

It is often thought that a lofty radio or television aerial attracts lightning. This is not really true and, indeed, the opposite could be the case.

The accepted method of protecting tall buildings against lightning is by the use of the so-called lightning conductor. This is a robust copper rod, pointed at the top end and attached to the highest point on the building. It is given a very good low-resistance connection to earth through a heavy copper ribbon. Its purpose is not to act as a lightning "conductor"—this would occur only in the extreme case of the rod being actually "struck". It achieves its object of protection in a less spectacular manner by making it possible for the electrical charges in a closely situated thunder-cloud to drain away to earth safely before they build up to the high electrical level necessary to instigate a lightning flash.

It is often discovered that lightning attacks the chimneys of houses, and this is not necessarily because the chimney is the highest point. The real reason is that the temperature of the air inside the building during an electrical storm is usually above that outside the building. This encourages a flow of

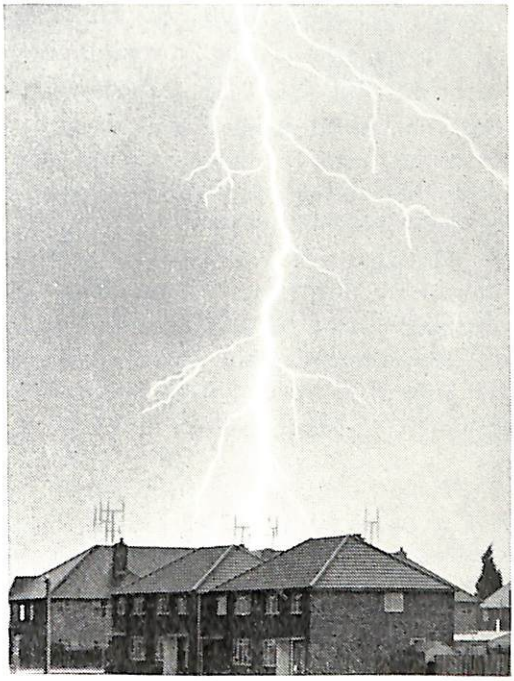


FIG. A.2. *Lightning discharge over houses during a severe storm. The main discharge is to earth behind the houses in spite of the television aerials on the chimney stacks.* (*Photo: Peter Berry, Kidlington, Oxford.*)

warm air from the chimney, even though there is no fire in the grate. This current of slightly moist, warm air forms an invisible cloud near the chimney of a nature that affords an easy target for lightning. This is because the cloud becomes a little ionized and somewhat conductive.

Now, if a television aerial is situated on the chimney—even though it is not as efficiently earthed as the lightning conductor—the electrical charge encouraged by the ionization tends to disperse and thus dispel the conditions required for a lightning flash directly above the house.

The few cases of damage to television equipment by lightning have often been caused by an abnormally heavy discharge from the aerial through the set and back to the mains supply. This can be avoided by pulling out the mains plug during a storm and ensuring that the aerial as a whole is efficiently bonded to a good earth by the shortest possible route, taking care to avoid sharp bends in the earth wire and making sure that the wire is of a large diameter: the larger diameter, the better in theory.

If the aerial is earthed in this way (the connection being made to the metal mast so that the parasitic elements and cross-booms are earthed), the downlead can be put out of the window if the storm is very local and very severe.

Even with an aerial that is not earthed in this manner, there is (or should be) a leakage path through the downlead, through the static discharge resistors which are connected in parallel with the isolating capacitors in the set, and through the set h.t. negative and chassis circuit to the mains supply, which is effectively earthed from the lightning point of view. Nevertheless, it is safer to make sure that the aerial is properly earthed.

If a television set is operated during an electrical storm, crackles will be heard on sound and flashes will be seen on the screen whenever lightning occurs. After the initial flash, a pattern of random white spots often develops on the picture, accompanied by a rushing noise on sound. This is the static charges picked up by the aerial discharging into the mains supply through the set. Fig. 1.16(*a*), on page 31, shows what this discharge effect is like, while Fig. A.2 shows a lightning discharge to earth.

APPENDIX VI

DX RECEPTION ON V.H.F. AND U.H.F.

Reception outside the service area is governed by tropospheric and ionospheric propagation effects (see Chapter 1), the former being influenced by close-to-earth weather conditions and the latter by conditions arising in the ionospheric layers, such as brought about by electrical storms, sun-spot activity, etc. The general effect is that the radio waves are bent back towards earth at distances greater than those consistent with ground-wave reception. Quite often, strong signals thus arrive at receivers well outside the normal reception range, depending on the height and refractive index of the signal bending medium.

So-called DX ("distant transmission") enthusiasts make it a hobby to pick up very weak radio and television signals from distant transmitters, while some viewers and radio listeners have to rely almost entirely on DX reception for their entertainment. The biggest problems of such reception are early-stage noise of the set and interference from less distant stations occupying an adjacent (or an identical) frequency. Set noise can be substantially reduced by the use of a low-noise transistor amplifier, while noise in the amplifier can be kept to a minimum by feeding the strongest possible aerial signal to its input.

Thus, a really good television aerial coupled to a good transistor amplifier can make a world of difference to poor pictures from weak signals. This is illustrated in Fig. A.3 which shows a u.h.f. Test Card transmission received over a distance of more than 65 miles with a 14-element Labgear aerial, and Fig. A.4, the same transmission as received through a Labgear transistor masthead amplifier. The grainy picture clearly shows how bad reception can be even on a high-gain 14-element array at this range, while the clearer picture reveals how "entertainment" reception emerges from the grain when a pre-amplifier is employed.

There are super-high-gain aerials designed particularly for weak signal areas and DX reception, especially on the u.h.f. bands. These are sometimes designed for maximum gain and directivity on one particular u.h.f. channel, or a special wide-band configuration may be adopted, such as the patented J-Beam "Parabeam" array which has a power gain some 58 per cent greater than a more conventional array of similar size and number of elements. The active element of the Parabeam is a skeleton slot which can be considered as behaving as two end-fed dipoles stacked approximately $\frac{5}{8}$-wavelength apart and joined in parallel at their 600 ohm terminals, thereby giving an

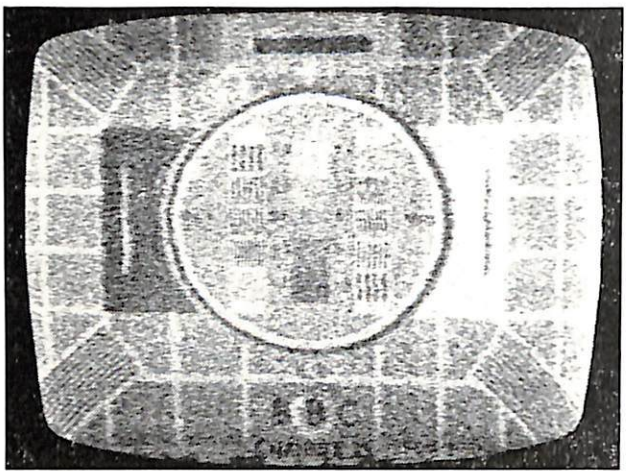


FIG. A.3. *U.h.f. signal as received direct on a Labgear* 14*-element aerial, at a distance of over* 65 *miles. (Photo: Labgear Ltd.)*

overall impedance of 300 ohms. This is transformed down to transmission-line impedance by a quarter-wave balun. The reflector system is also of skeleton slot design, and this, in conjunction with the tuning and spacing of the directors, endows the array with high-gain, wideband features and a good front-to-back ratio. The "Multibeam" is even better (p. 85).

Another DX u.h.f. aerial is the "Explorer" made by Antiference Ltd. When such an aerial was set up in a hilly location in the West Country some 80 miles from a u.h.f. transmitter, "entertainment" reception could be obtained under certain weather conditions (tropospheric influenced), using a set-side booster. It is sometimes found that better DX reception is possible by a single in-line array rather than a broadside array, especially in hilly country—this has been proved a number of times by the author when

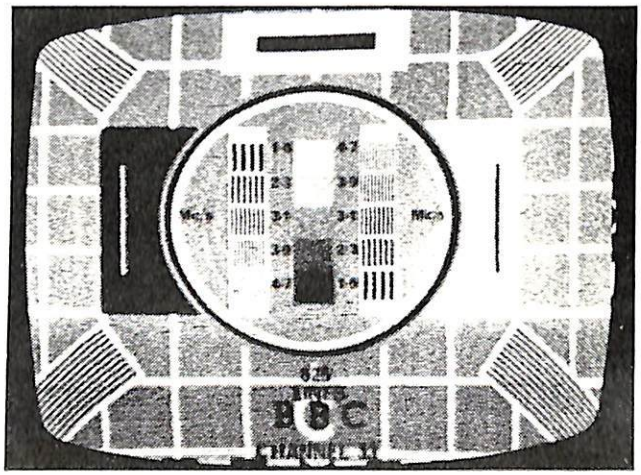
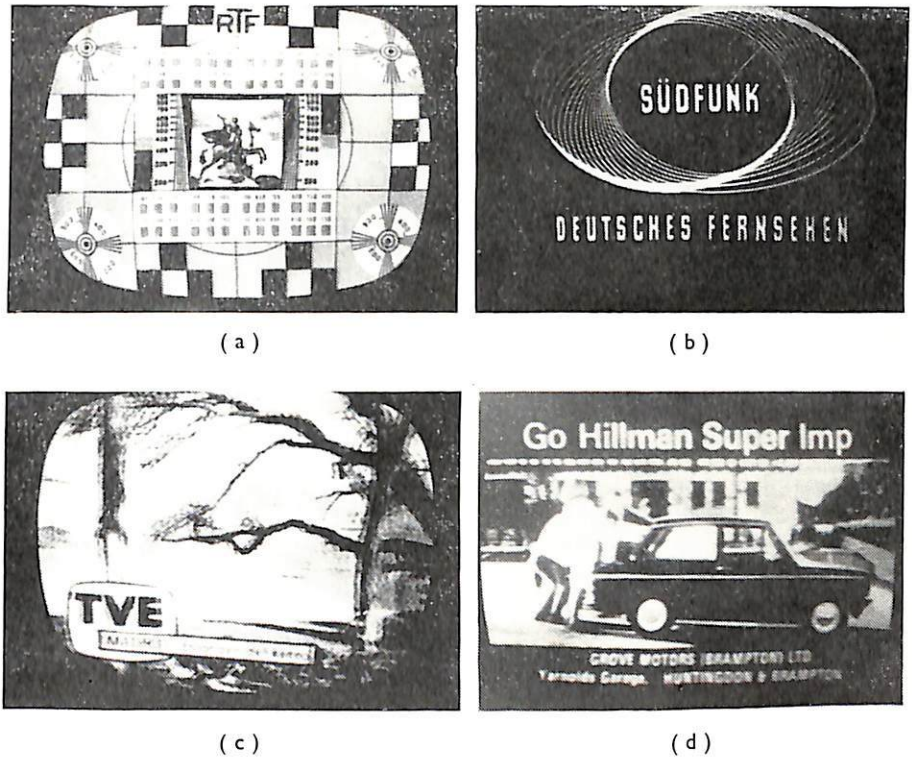


FIG. A.4. *The same signal as in Fig A.*4*, but received with the aid of a Labgear masthead amplifier. (Photo: Labgear Ltd.)*



(a) (b)

(c) (d)

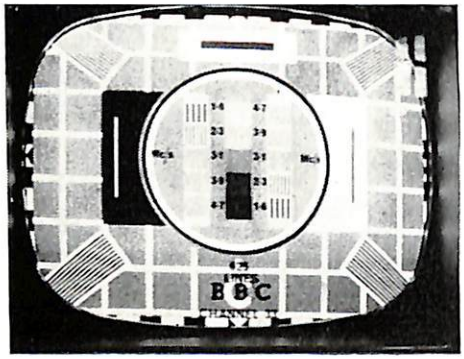
FIG. A.5. *DX pictures of European television signals on the v.h.f. channels as received in Holland, using a rotatable aerial array. Details are given in the text.*

making DX u.h.f. tests. The best quality, low-loss downlead is, of course, essential for DX reception.

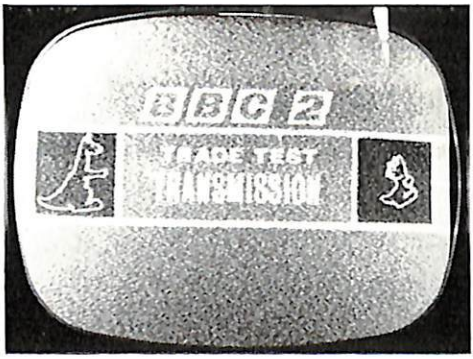
DX reception is also possible on the v.h.f. channels in Bands I and III, and reception of BBC and ITV transmissions has been reported as far afield as South Africa and Southern Rhodesia as well as in Europe. For example, Fig. A.5 shows some results obtained by Mr. J. J. Mink of The Hague, Holland, who uses an aerial system about 27 ft high and 75 ft above sea level. The two top aerials of his array are arranged to rotate under the remote control of an electric motor. Receivers used are switchable over four line standards and the King V.H.F. Telebooster is in frequent use.

The pictures show (*a*) an 819-line signal from France (Lille), (*b*) a German 625-line signal, (*c*) a Spanish 625-line signal—with a trace of multipath interference—and (*d*) a British 405-line ITV signal. All except (*c*) were obtained with use of the King Telebooster.

From another site in Holland come the DX u.h.f. pictures reproduced in Fig. A.6. Some idea of the remarkable quality of the transmissions is given



(a)



(b)

(c)

FIG. A.6. *DX pictures of European television signals on the u.h.f. channels as received in Holland, using a mast-head u.h.f.-to-v.h.f. converter to reduce transmission line losses. Details are given in the text.*

FIG. A.7. *Off-screen photo of colour transmission on Channel* 24 *taken by the author at his site* 180 *ft above sea-level and a distance of* 100 *miles from the station. Set Pye hybrid and aerial Multibeam*

by the Test Card at (*a*). Another, less clean, signal is shown in (*b*), while at (*c*) is a really first-class u.h.f. picture of a German transmission. These pictures were obtained by Mr. G. N. Adama, whose method of u.h.f. DX-ing employs a complete transistorized u.h.f.-to-v.h.f. converter directly below the 52-element aerial at the masthead. Thus, the losses imposed by the downlead are somewhat less at the translated v.h.f. channel than they would be at u.h.f. direct. The converter is tuned remotely from the receiver by a reversible electric motor.

An interesting picture of a colour transmission photographed from the screen of the author's set is shown in Fig. A.7. This was received at an altitude of 180 ft above sea-level on a Multibeam Aerial (J-Beam Aerials Ltd.) over a linear distance of 100 miles on Channel 24, with boost applied by a King U.H.F. Telebooster. Such reception, however, is not consistent, but varies from virtually zero to 1 mV or more at the aerial socket.

APPENDIX VII

U.H.F. STATIONS CARRYING ITA 625-LINE COLOUR/MONOCHROME TRANSMISSIONS BY ABOUT THE END OF 1970

Station No.	*Station*	*ITA Target Date*	*ITA Channel*	*BBC1 Channel*	*BBC2 Channel*	*Unallocated Channel*	*Aerial Group*
101	CRYSTAL PALACE	1969	23H	26	33	30	A
101.1	Guildford	1970	43V	40	46	50	B
101.3	Reigate	1970	60V	57	63	53	C
101.4	Tunbridge Wells	1970	41V	51	44	47	B
101.5	Hemel Hempstead	1970	41V	51	44	47	B
	Coverage of the 101 series of stations will include the main London area extending roughly to St. Albans, Bishop's Stortford, Southend-on-Sea, Tunbridge Wells, Camberley, and Slough, etc. Later there will be other relays covering areas of low signal from Crystal Palace.						
102	SUTTON COLDFIELD	1969	43H	46	40	50	B
102.3	Brierley Hill	1970	60V	57	63	53	C
102.6	Bromsgrove	1970	24V	21	27	31	A
102.11	Stoke-on-Trent (Fenton)	1970	24V	21	27	31	A
	The 102 series will cover Birmingham, Coventry, Rugby, Derby, Burton-on-Trent, Stoke-on-Trent, Wolverhampton, Droitwich, etc.						
103	WINTER HILL	1969	59H	55	62	65	C
103.2	Nelson/Colne (Pendle Forest)	1970	25V	22	28	32	A
	The 103 series will cover South Lancashire and most of Cheshire.						
104	EMLEY MOOR	1969	47H	44	51	41	B
104.1	Wharfedale	1970	25V	22	28	32	A
104.3	Sheffield	1970	24V	21	27	31	A
104.5	Chesterfield	1970	23V	33	26	29	A
	The 104 series will cover such urban centres as Bradford, Leeds, Northallerton, York, Selby, Market Rasen, Lincoln, Mansfield and Sheffield.						
105	BLACK HILL	1969	43H	40	46	50	B
	The 105 series for Central Scotland covers Glasgow, Paisley, Lanark, Alloa, etc., although much of Edinburgh and district is within range of this transmitter, this area will later be served by a main transmitter at Craigkelly.						
106	WENVOE	1970	41H	44	51	47	B
106.1	Kilvey Hill	1970	23V	33	26	29	A
	The Wenvoe transmitter will provide coverage of Cardiff, Newport, Barry and Bridgend, etc., with Kilvey Hill extending coverage to the Swansea area.						
107	DIVIS (Belfast)	1970	24H	21	27	31	A

U.H.F. COLOUR/MONOCHROME STATIONS BY 1970

Station No.	*Station*	*ITA Target Date*	*ITA Channel*	*BBC1 Channel*	*BBC2 Channel*	*Unallocated Channel*	*Aerial Group*
108	ROWRIDGE	1969	27H	31	24	21	A
	This transmitter, on the Isle of Wight, will cover many South Coast areas including Southampton, Portsmouth, Bognor Regis, Bournemouth, Swanage, Eastleigh, etc.						
109	PONTOP PIKE	1970	61V	58	64	54	C
	North-east England including Sunderland, Wallsend, Blythe, etc.						
110	MENDIP	1970	61H	58	64	54	C
	Coverage for most of Somerset and parts of Gloucestershire and Wiltshire.						
111	WALTHAM	1970	61H	58	64	54	C
	Coverage of such areas as Grantham, Loughborough, Melton Mowbray, Nottingham and Newark-on-Trent.						
113	DOVER	1969	66H	50	56	53	D
	Coverage of such areas as Dover, Folkestone, Ramsgate, Margate, Canterbury, Hythe and Rye.						
114	TACOLNESTON	1970	60H	57	63	53	C
	Coverage of such areas as Norwich, Great Yarmouth, Lowestoft, Bury St. Edmunds and Thetford.						
117	BECKLEY (Oxford)	1970	60H	57	63	53	C
	Coverage includes Oxford, Aylesbury, Swindon, Abingdon, etc.						

Many more main and relay stations will come into operation in the period 1971 onwards. Main stations have radiated powers of from 100 to 1,000 kW.

H = aerial horizontally polarized V = aerial vertically polarized

Based on information supplied by ITA Engineering Information Service. (See also Table 3.7 on page 87.)

APPENDIX VIII

STATIONS SCHEDULED FOR THREE-PROGRAMME WORKING IN 1971

Station	*BBC1 Channel*	*BBC2 Channel*	*ITA Channel*	*Aerial Group*
Belmont (East Lincoln)	22H	28H	25H	A
Bilsdale (N. Yorks)	33H	26H	29H	A
Caldbeck (Cumberland)	30H	34H	28H	B
Caradon Hill (E. Cornwall)	22H	28H	25H	A
Craigkelly (E. Lothian)	21H	27H	24H	A
Durris (Kincardineshire)	22H	28H	25H	A
Hannington (Hampshire)	39H	45H	42H	E
Heathfield (E. Sussex)	49H	52H	64H	D
Redruth (Cornwall)	51H	44H	41H	B
Sandy Heath (Bedfordshire)	21H	27H	24H	A
Selkirk (Selkirkshire)	55H	62H	59H	C
Sudbury (Suffolk)	51H	44H	41H	B

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